The
ENGINEER DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XIX No. 9 SEPTEMBER, 1958

ENGINEERING DIGEST:

~~MR. A.E.V. LONG~~
~~MR. W.F.C. SCHAAP~~
~~MR. T.B. WEBB~~
MR. W.R. HARVEY
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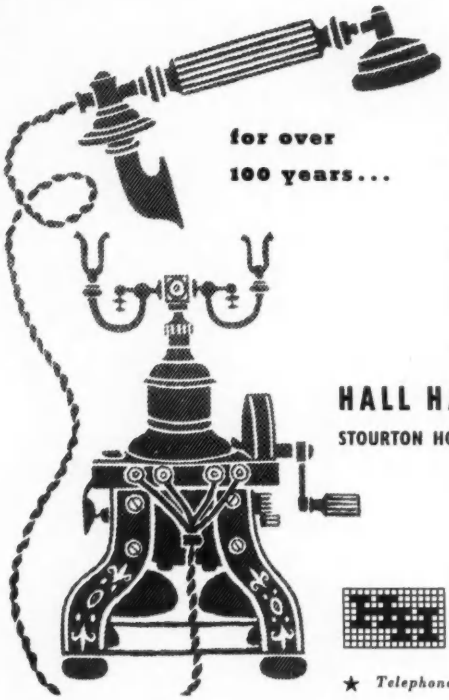

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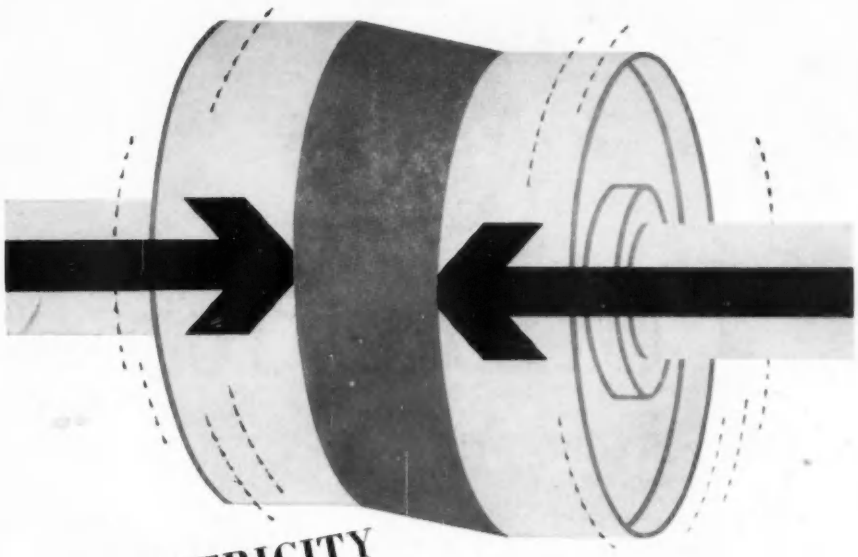

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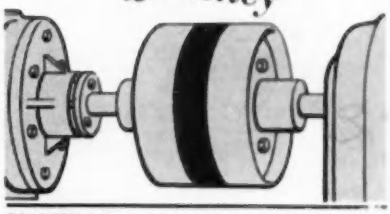

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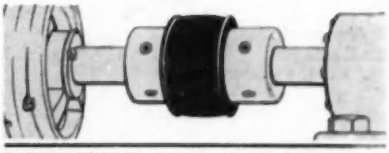

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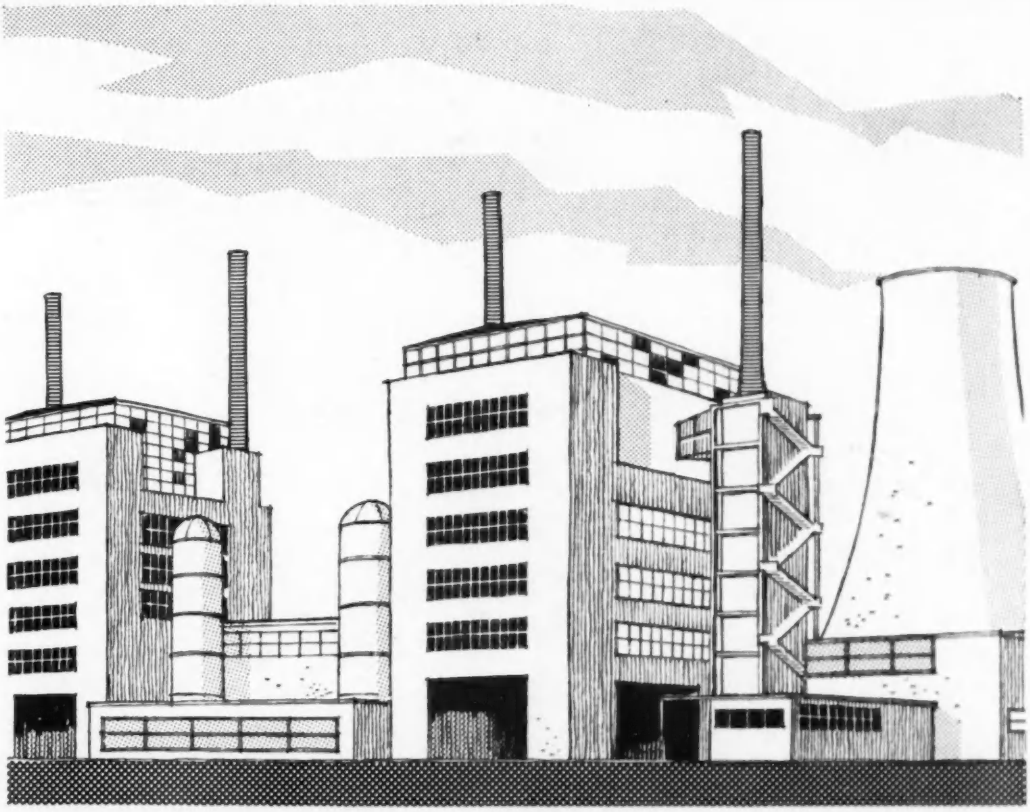

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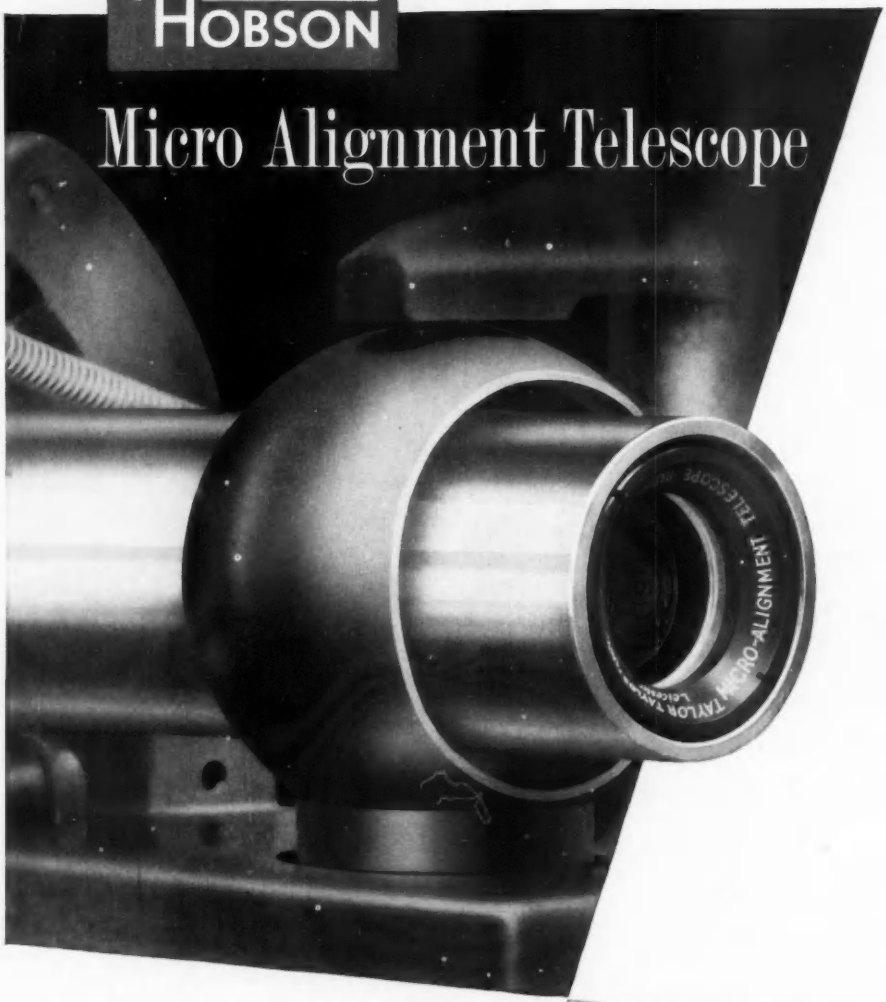

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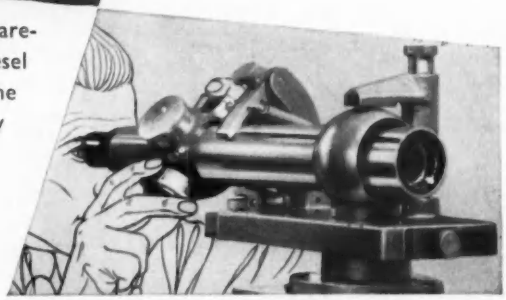

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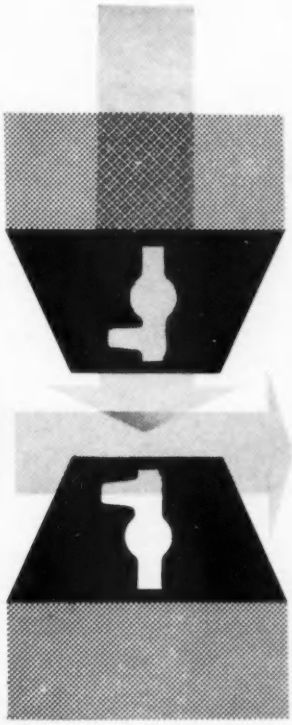

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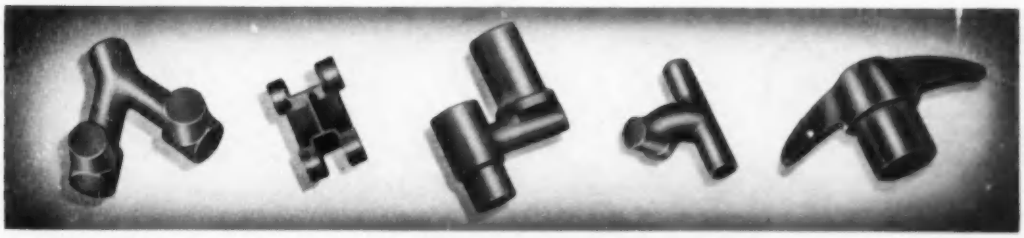

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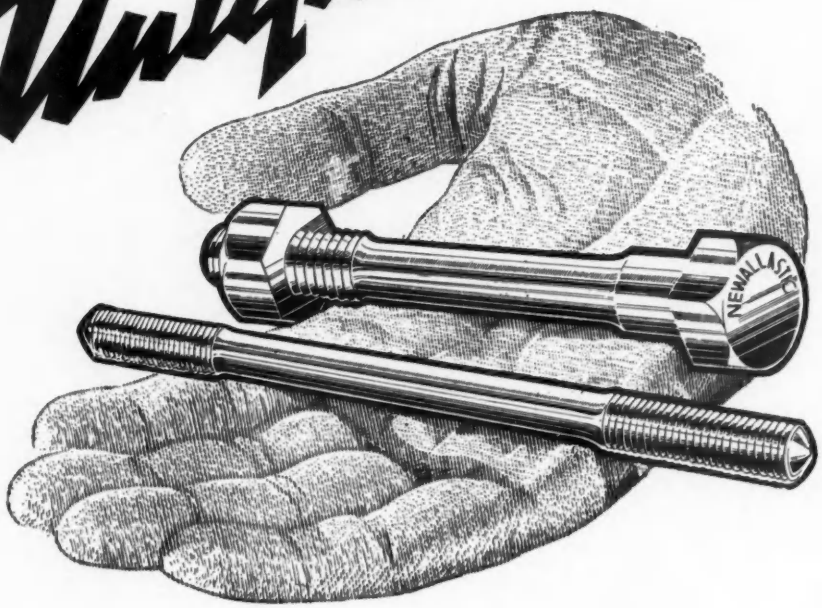

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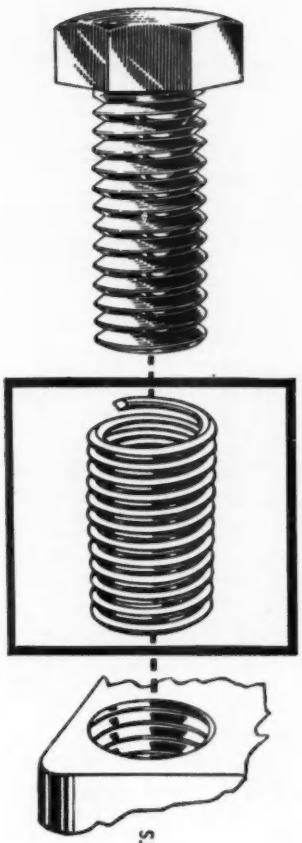

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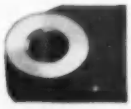
DRILL **TAP** **INSTALL** 

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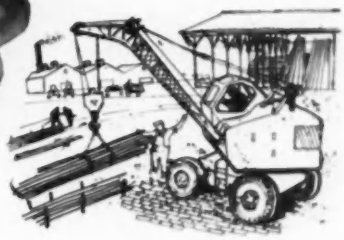

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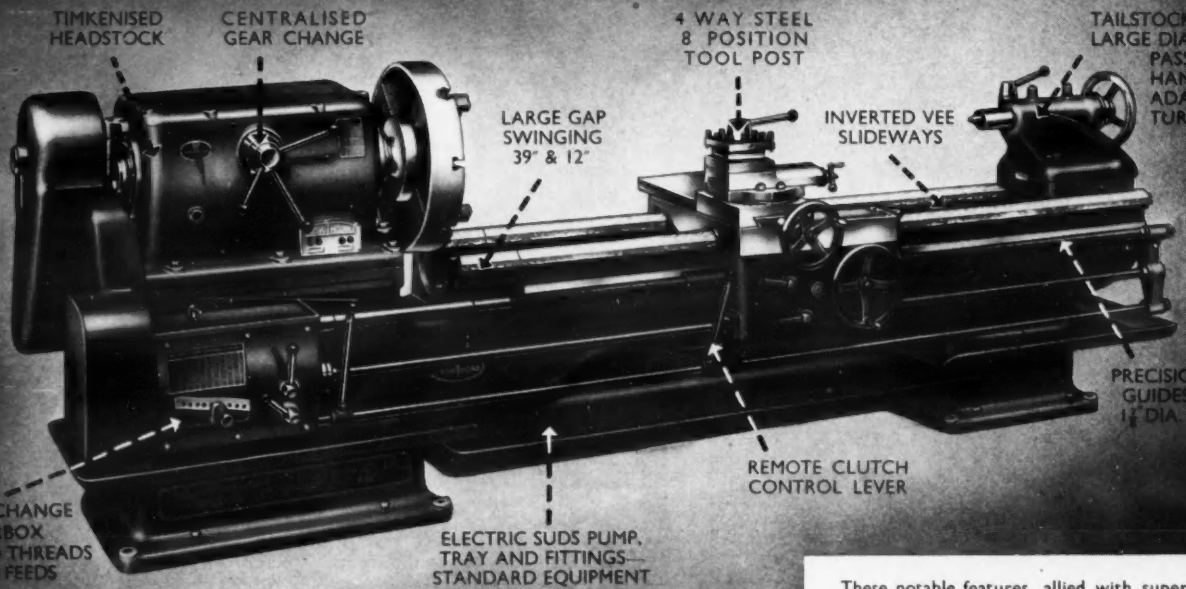
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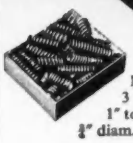

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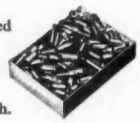

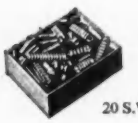

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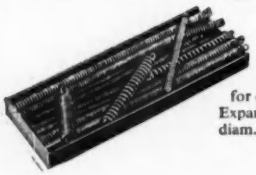

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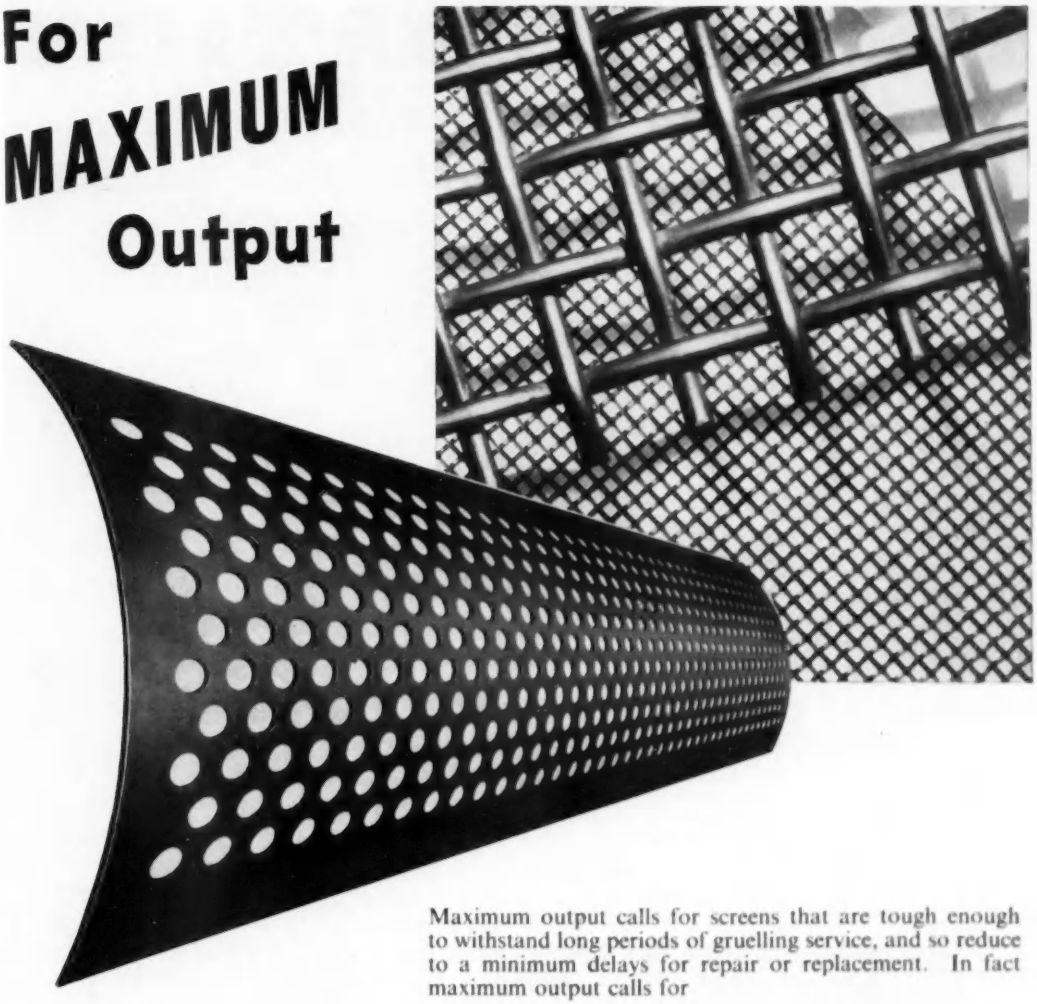

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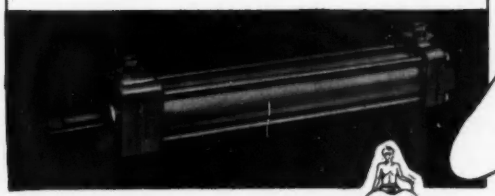

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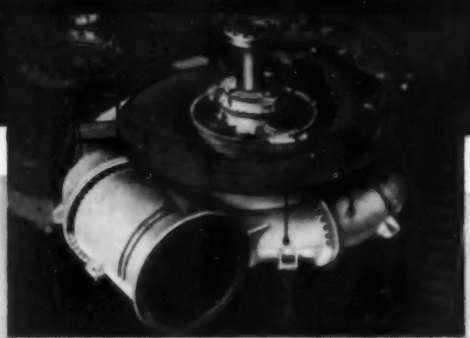

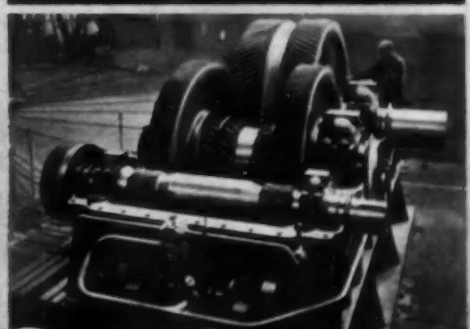

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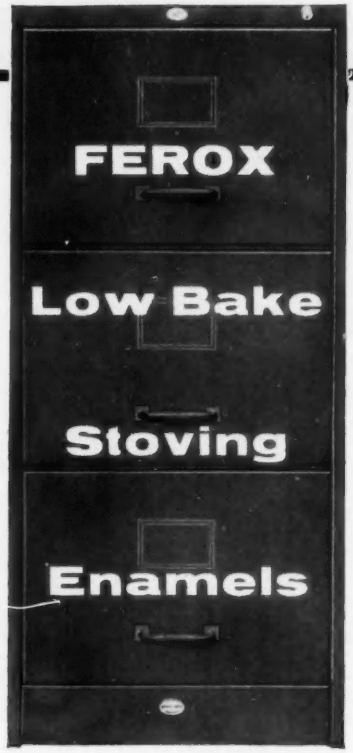

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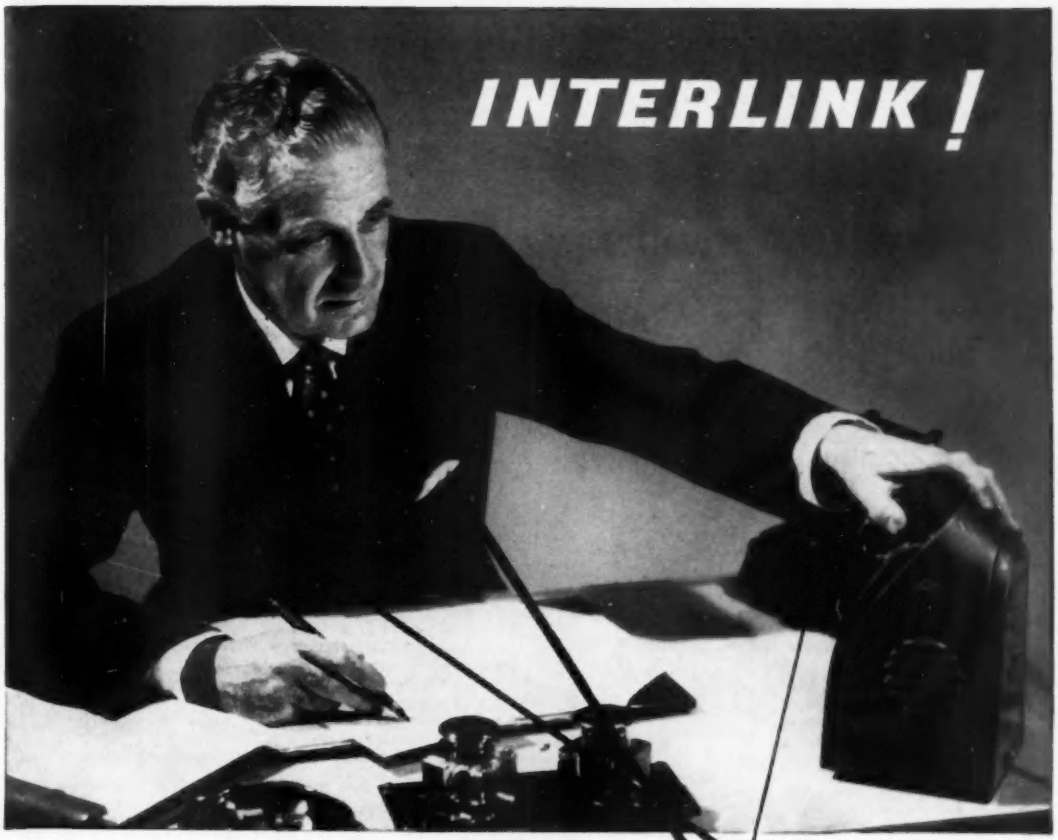

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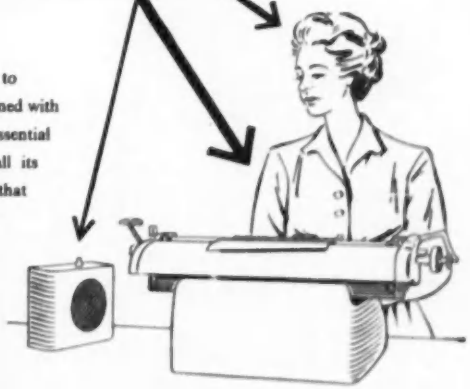

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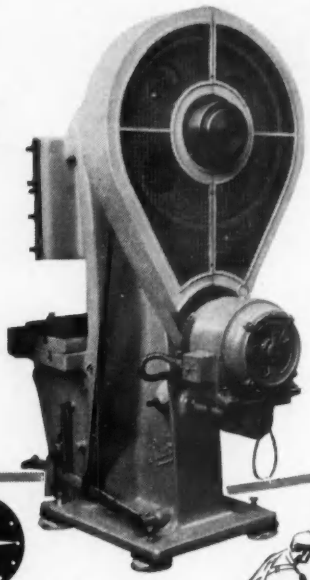
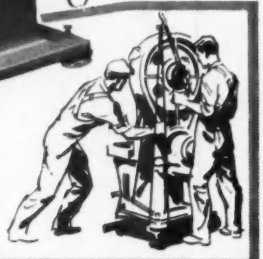
BREAKING INSTALLATION RECORDS WITHOUT BREAKING THE FLOOR

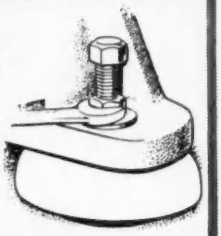


2.0. p.m. Problem. How to get this 50 ton press installed and working with the least possible production delay. How to hold it safe and levelled on an uneven floor riddled with pipe lines. Method chosen: Barrymount Levelling Machine Mounts, as specified by Cementation experts. Time taken:—**two hours ten minutes** This is how:—



3.15 p.m. Press in position. A "Barrymount" Machine Mount goes under each corner—bolted through the mounting hole. There's no grouting in: no rag bolting: no floorbreaking to be done at all.

3.45 p.m. Levelled. "Barrymount" Machine Mounts incorporate their own levelling device. The bolt is turned down and locked at precise levelling—exact to within a thou even on sloping or rough floors. No inexact and time-wasting shimming.



4.10 p.m. Working. No long expensive production delays while the concrete dries out. Directly the press is connected to power, it's ready to work. Its "Barrymount" Machine Mounts act as highly efficient shock and vibration isolators; hold it firm and safe without a sign of "walking".

Where did all this happen?
We've taken a typical problem here ; but it **could** happen in your machine shop. Cases like it crop up almost daily, all over the country, and they're all solved the same way.

"Barrymount" Machine Mounts were introduced here from the U.S. three years ago. Since then their use has spread to thousands of machine shops throughout Britain. Users report installation times cut from days to minutes ; floor space better used ; greater production flexibility and a dramatic decrease in structure-borne vibration and noise.

It's not uncommon for "Barrymount" machine mounts to pay for themselves at installation in terms of production time gained. It's pretty sure that a pilot set on the next machine you install—or move—could show you similar savings, too. If you'd like full technical details, get your secretary to fill in this coupon.

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LEVELLING MACHINE MOUNTS

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Please send me full details of "Barrymount" Levelling Machine Mounts.

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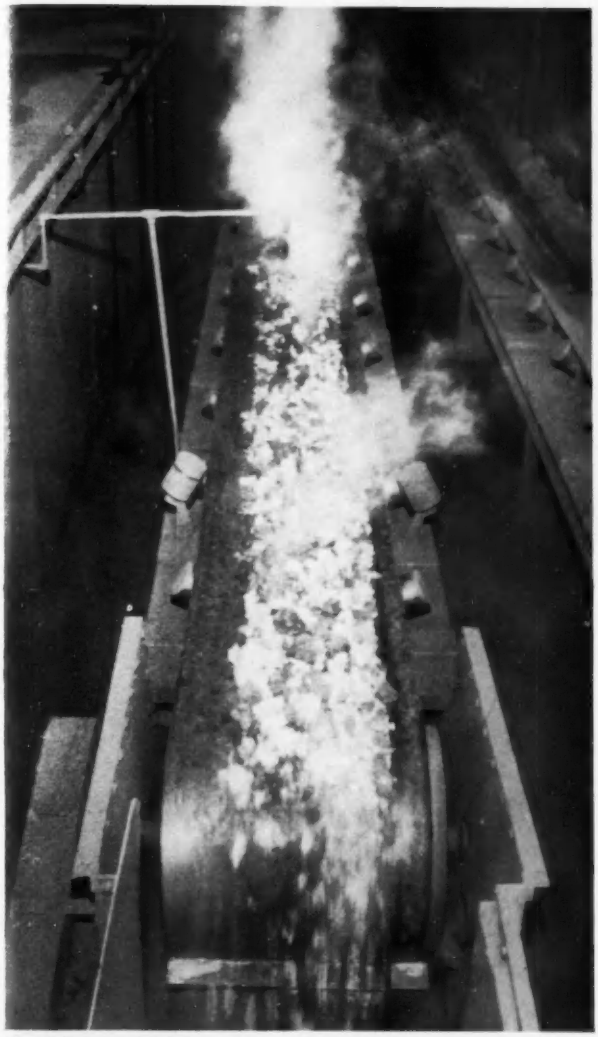
POSITION IN COMPANY .....

COMPANY'S NAME AND ADDRESS .....



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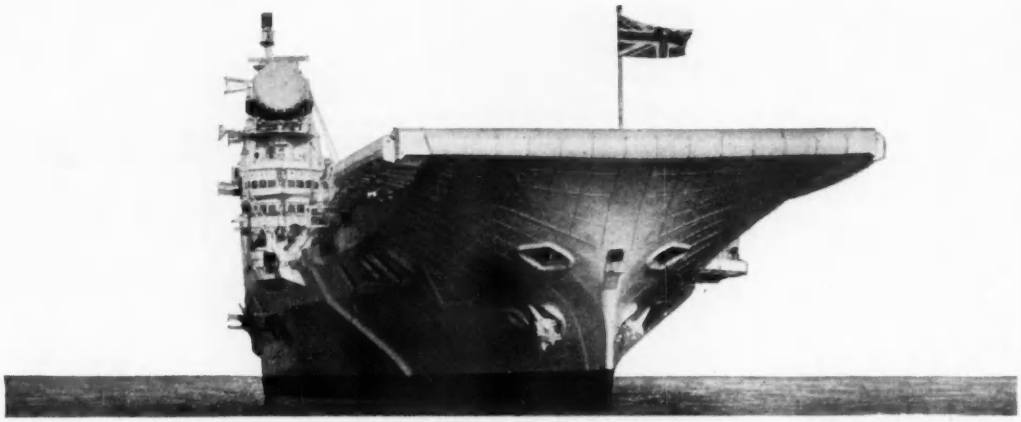

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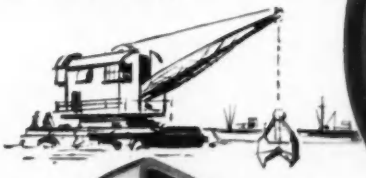

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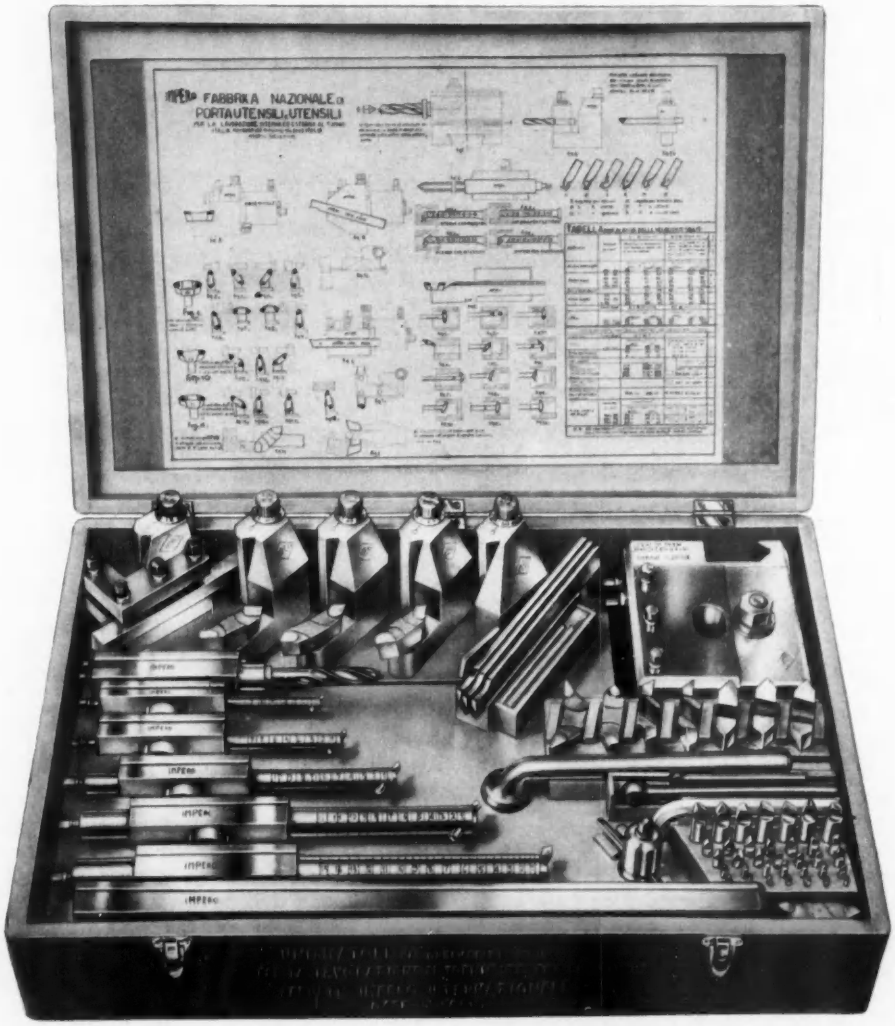

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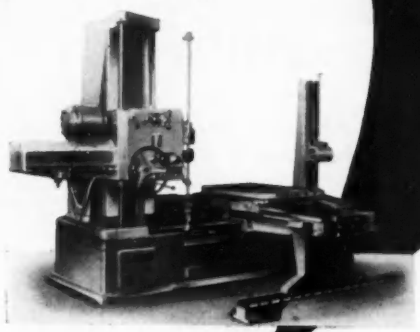
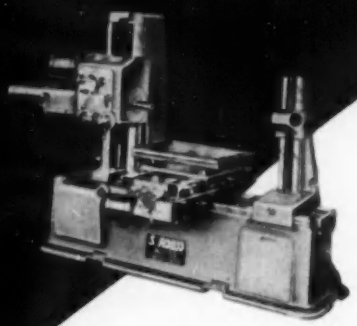
Net weight	6.7 tons





Horizontal Boring Machine Type AL 55

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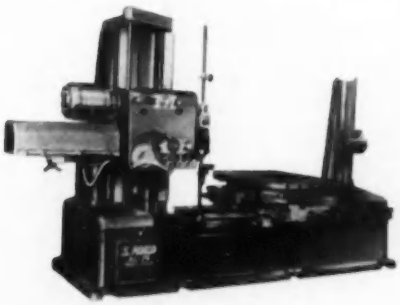

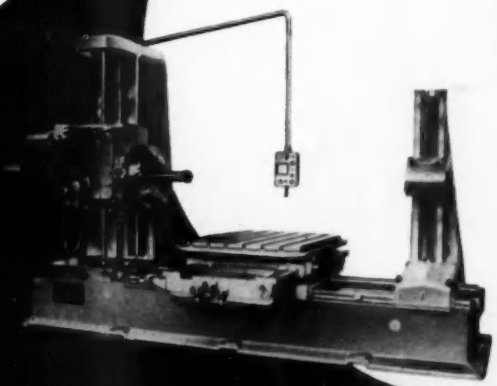

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Spindle dia.	3" 5 8
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Model 120 CLq.

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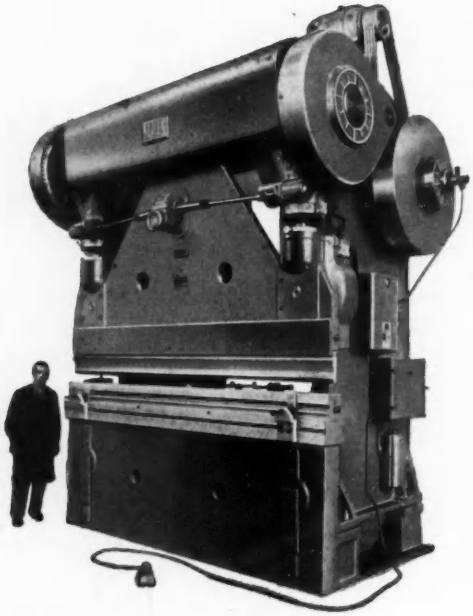

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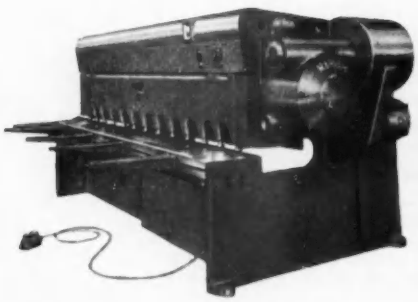

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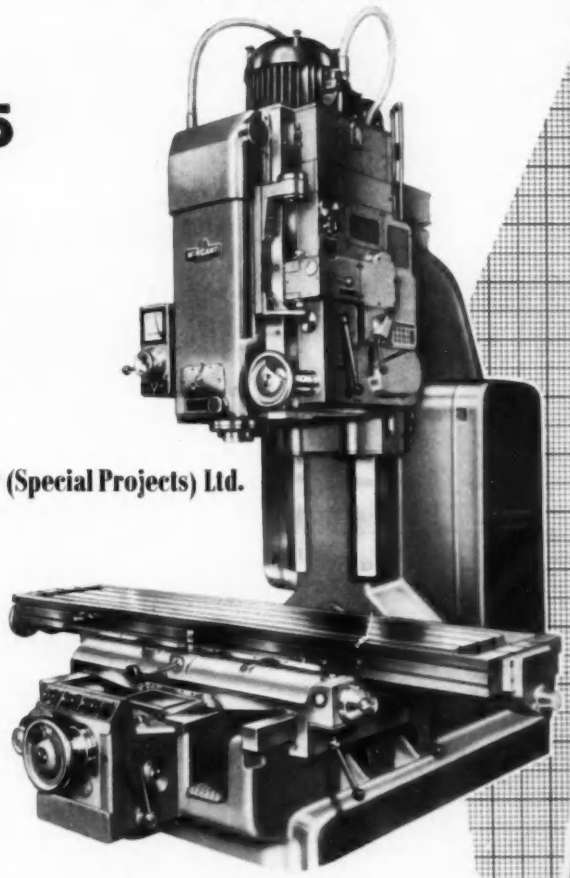

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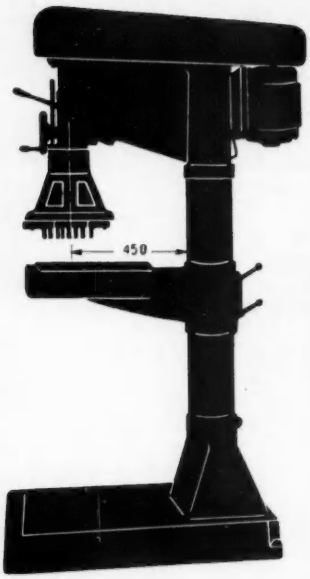

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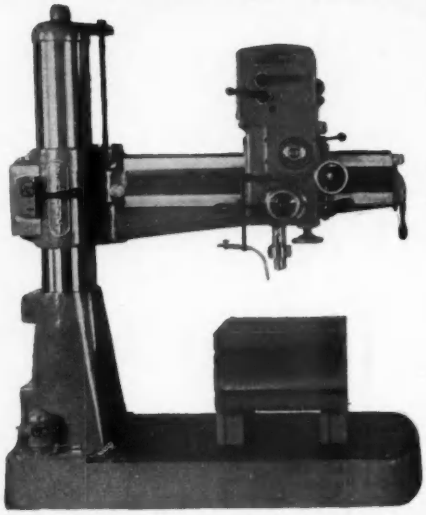

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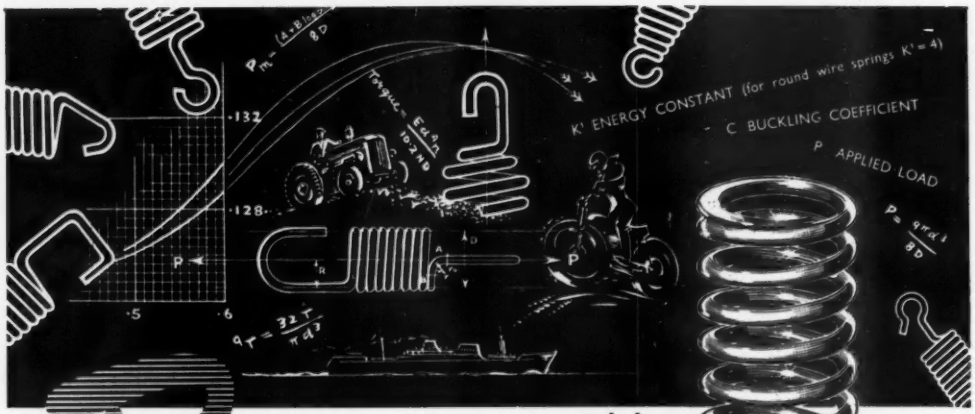

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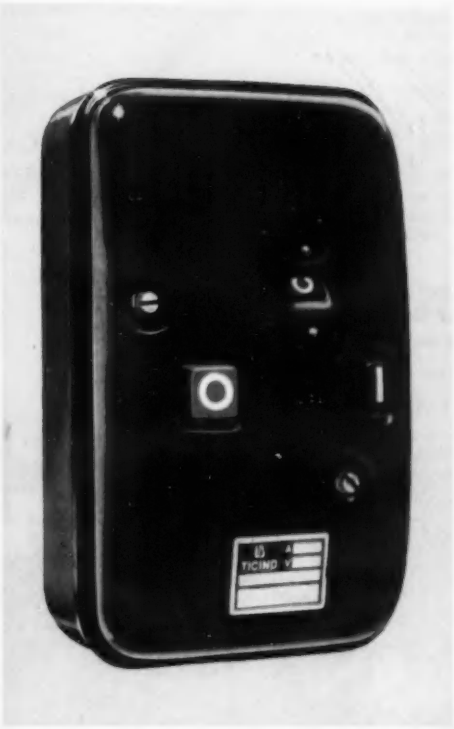

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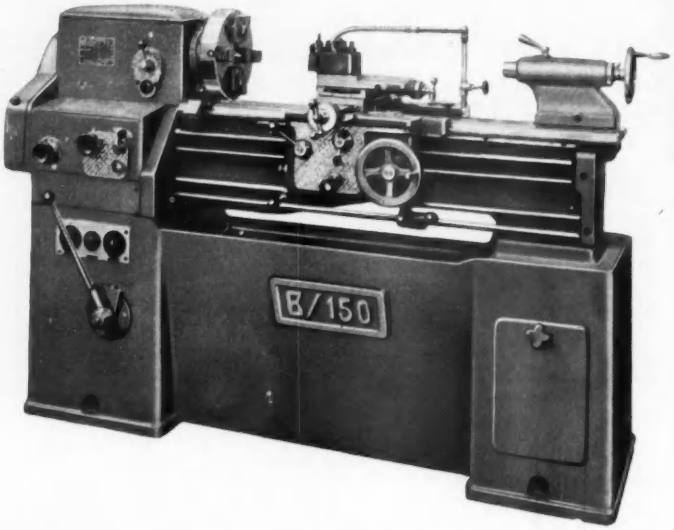

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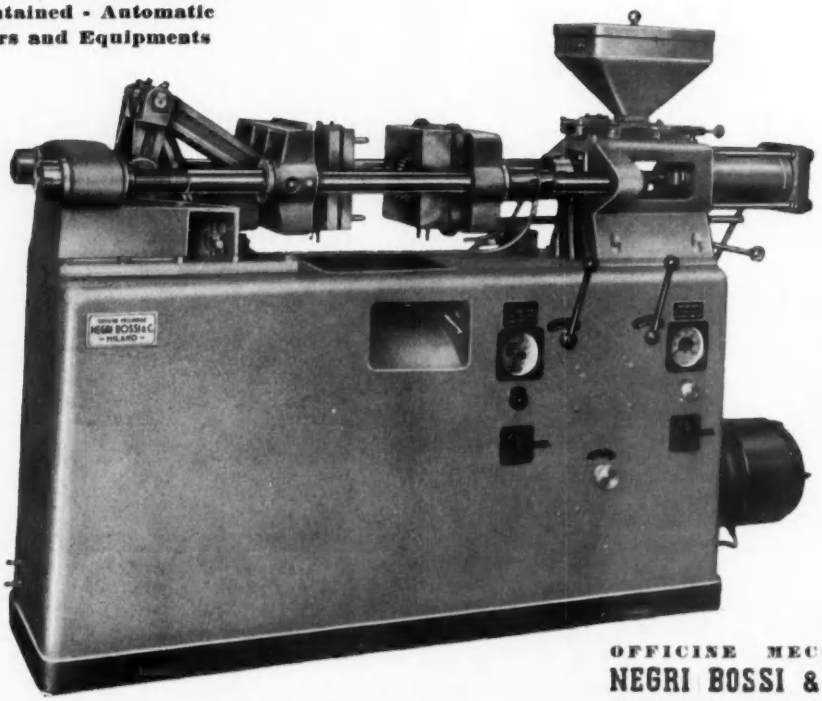

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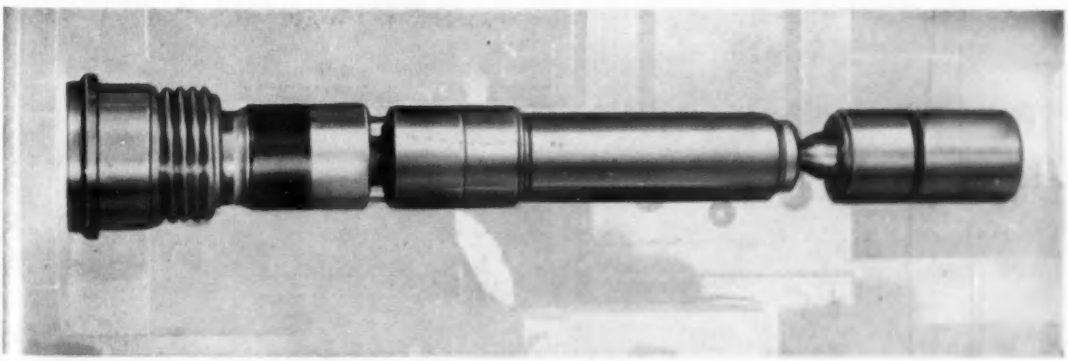

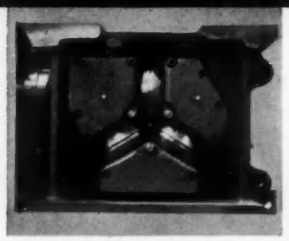

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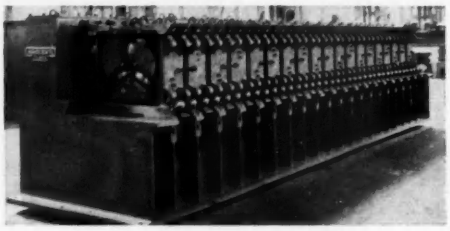
Stretch re



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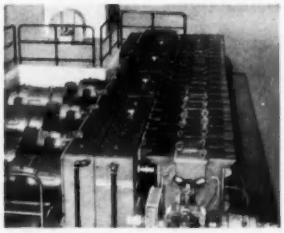

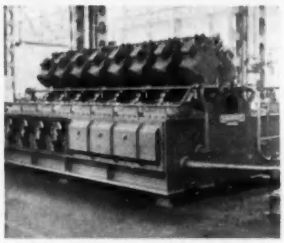

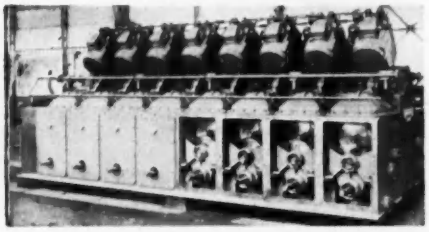

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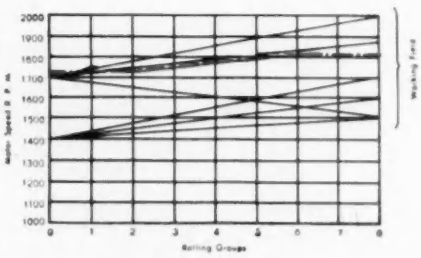

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A FOUR YEAR RUN . . .

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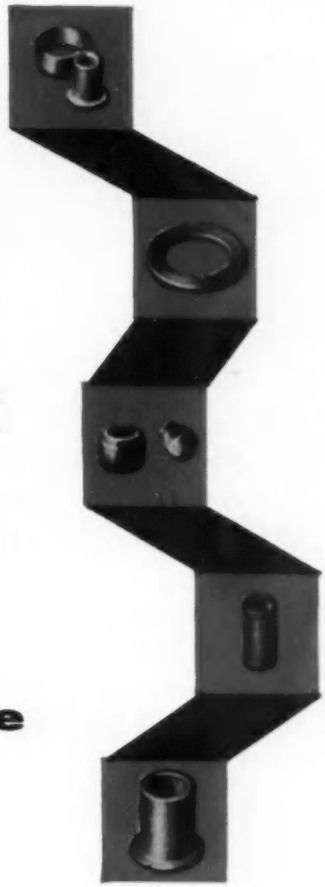

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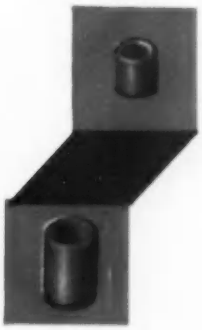

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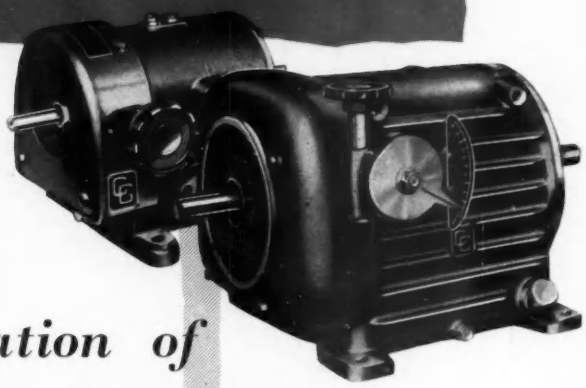

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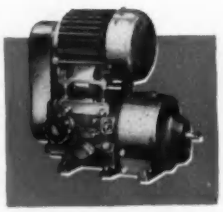

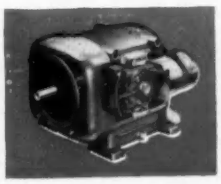

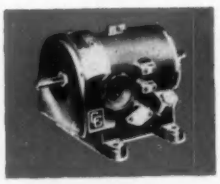

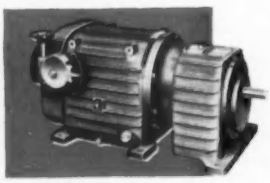

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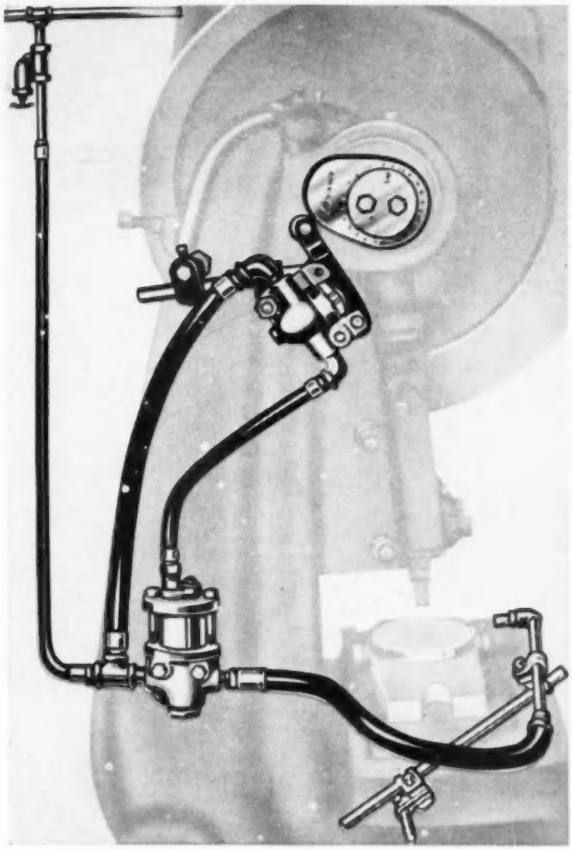

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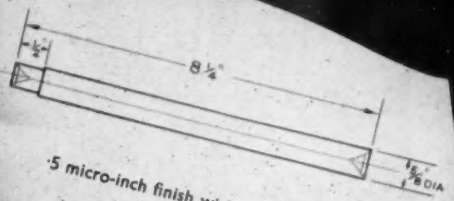

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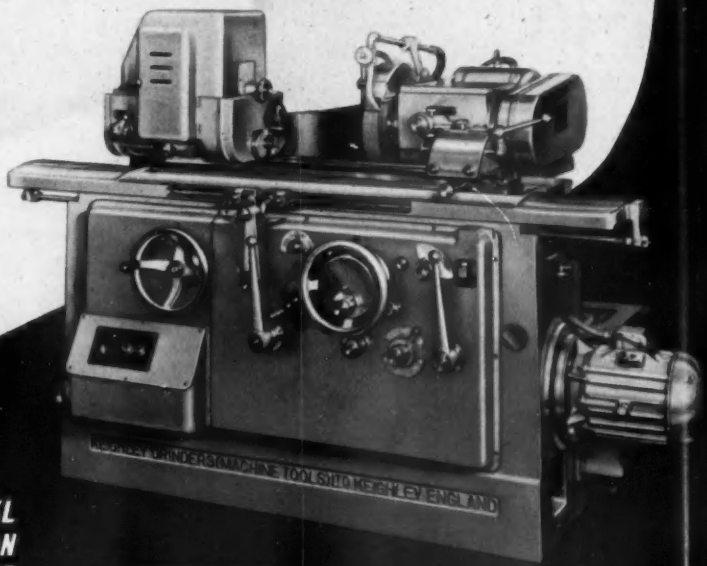

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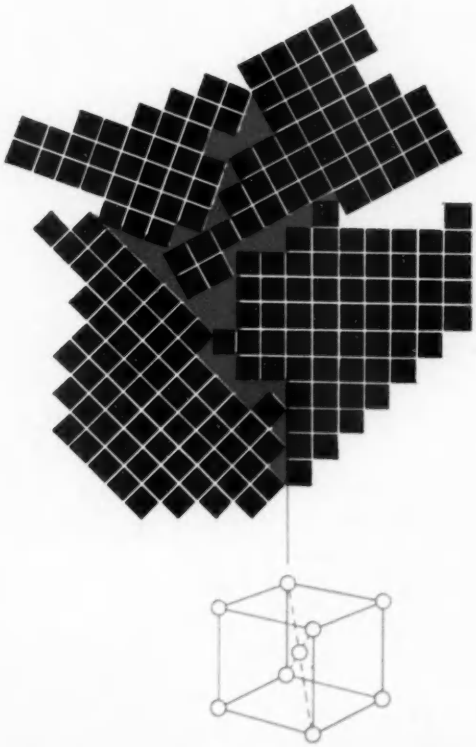
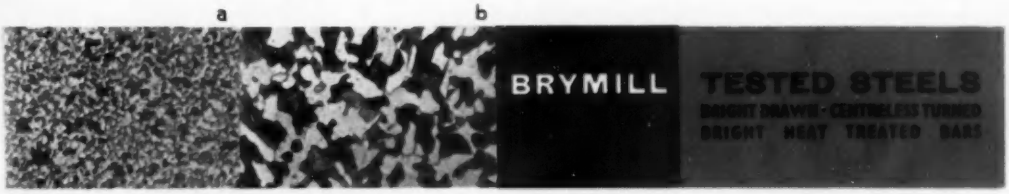


a b



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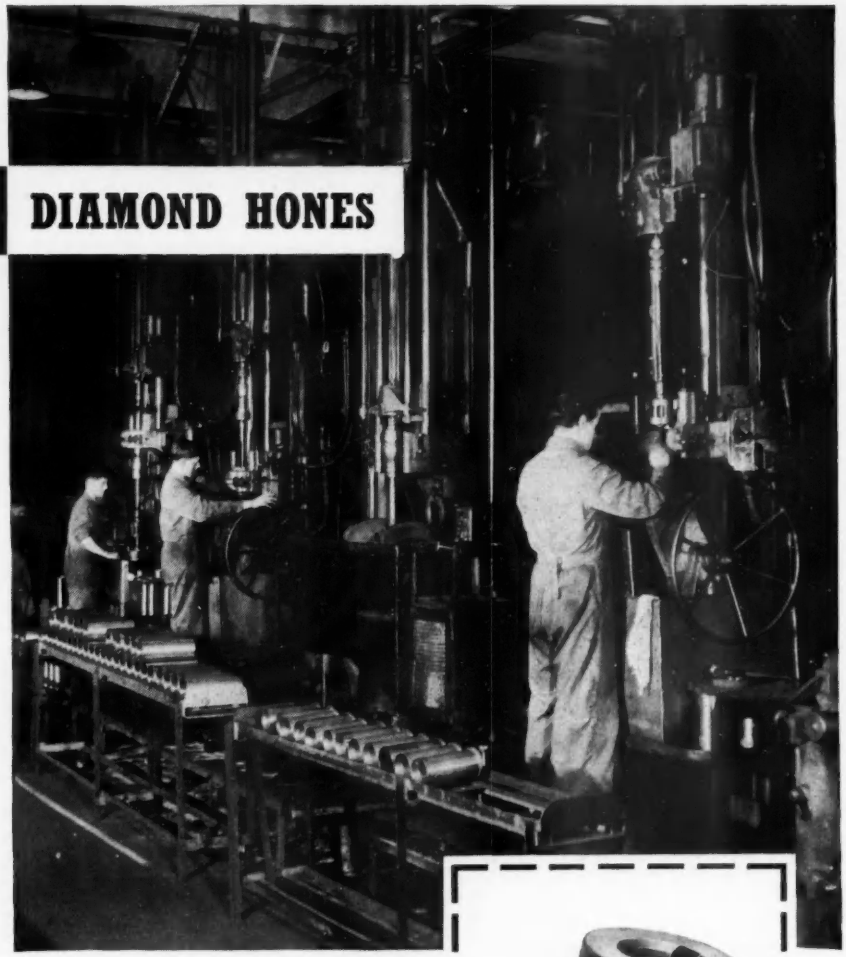

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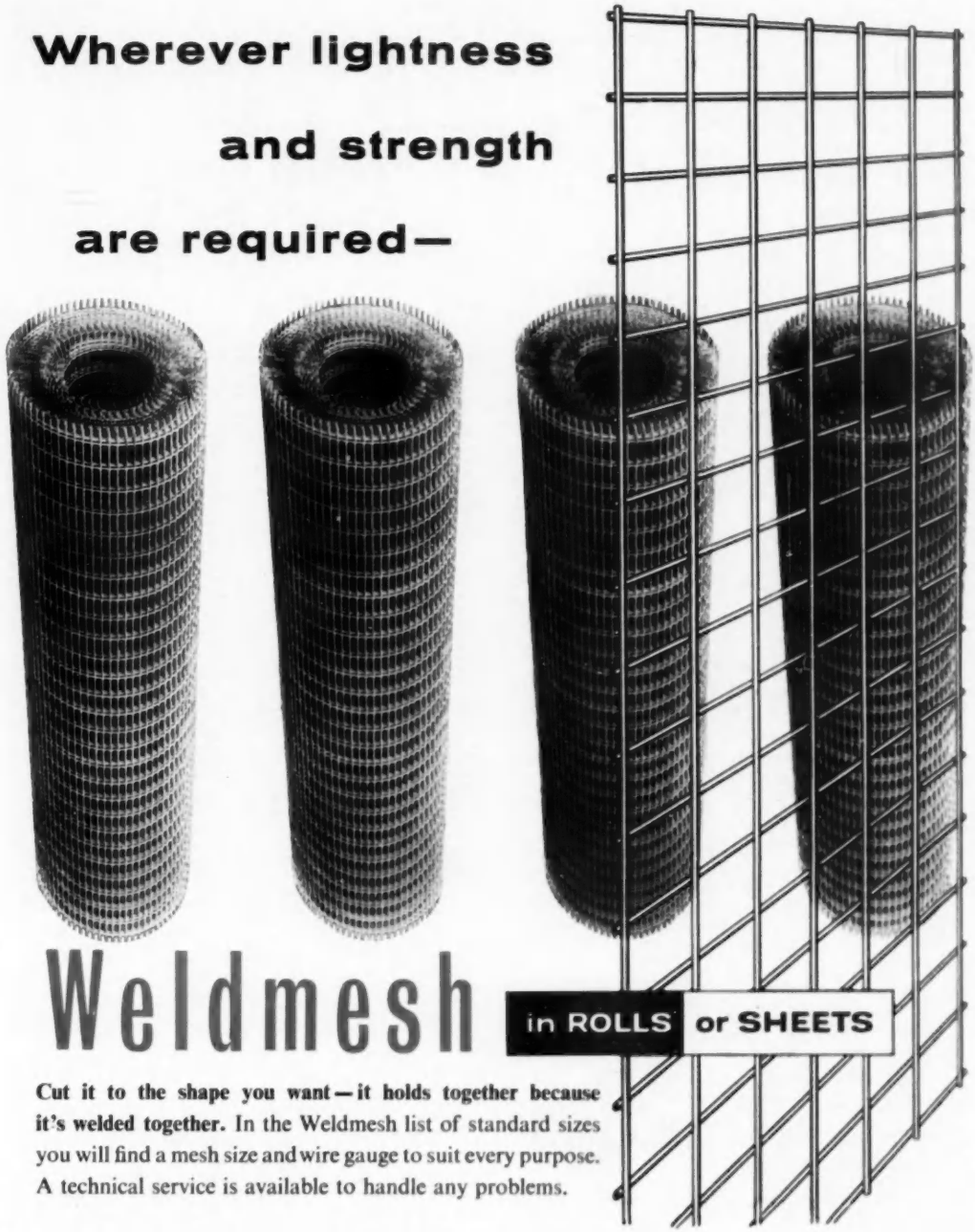

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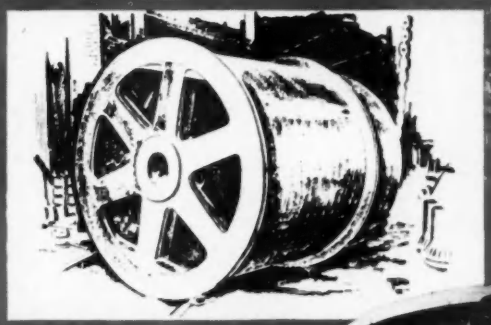

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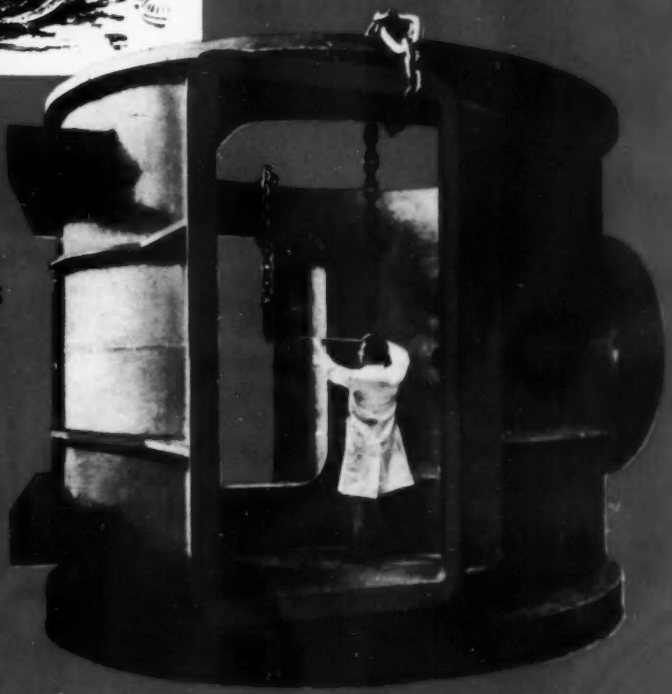

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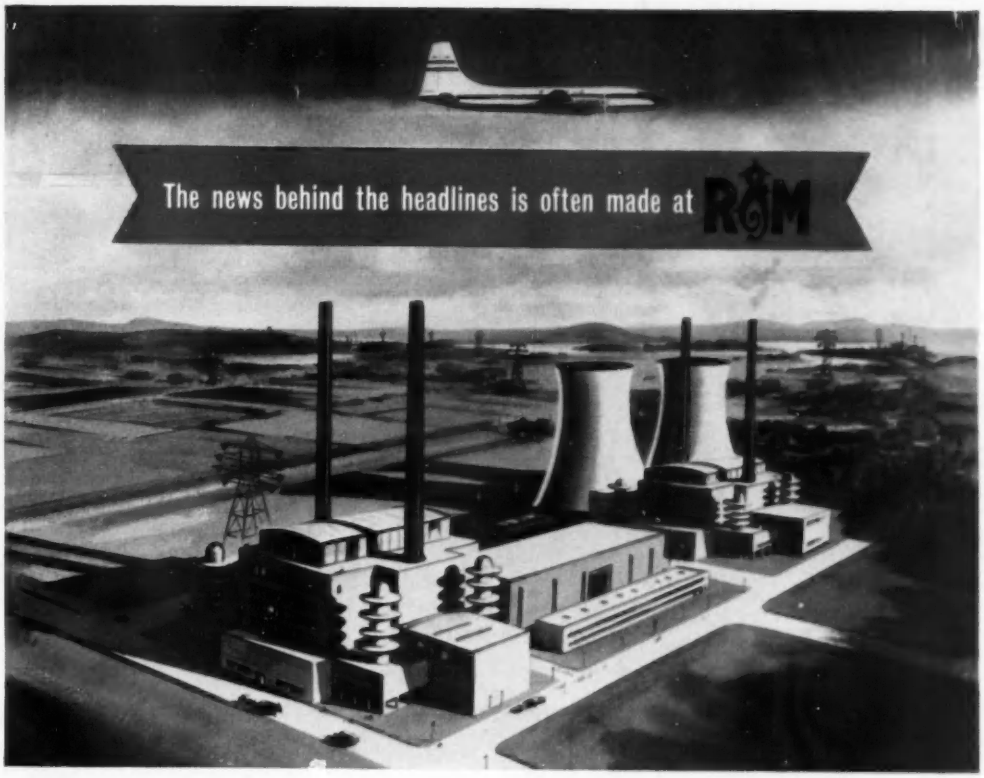

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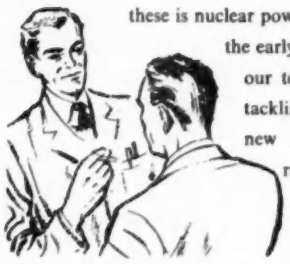

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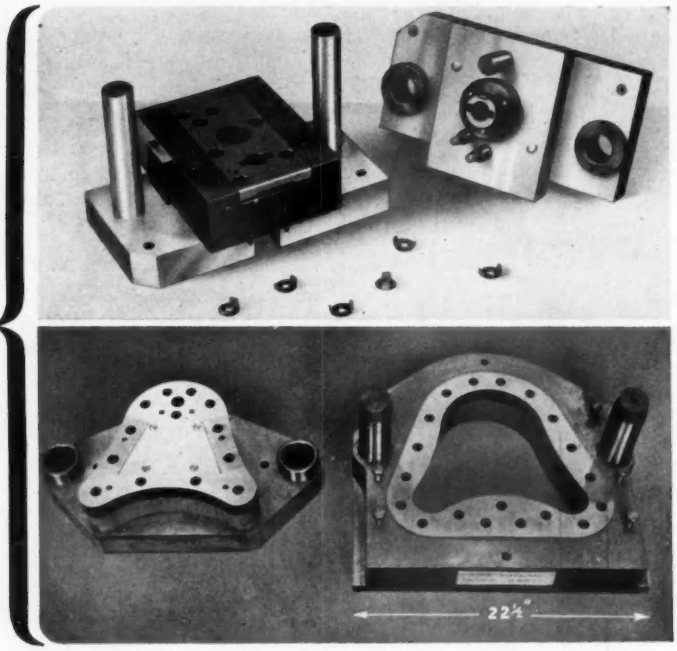

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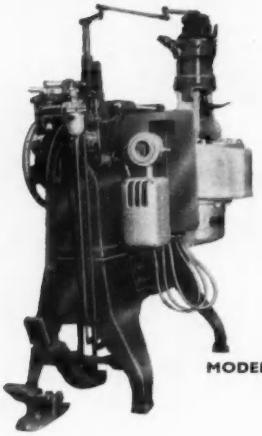

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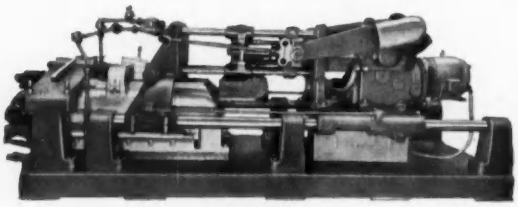

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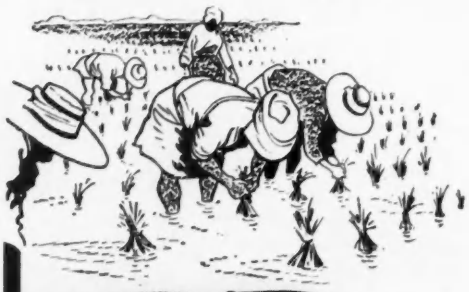

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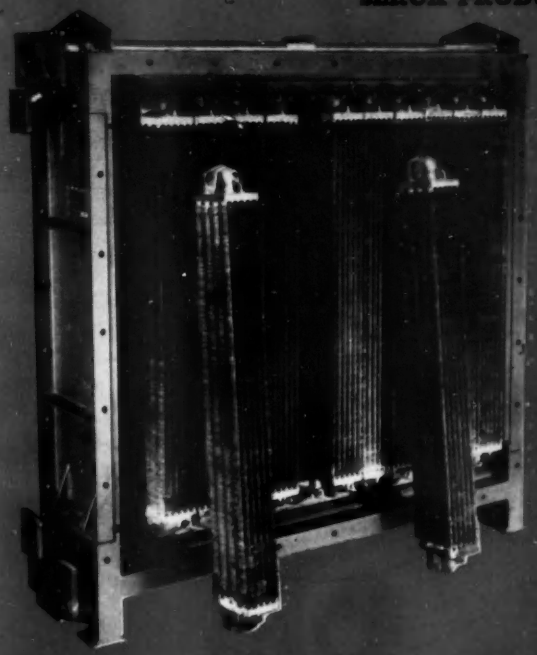

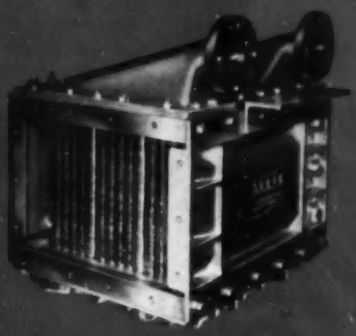

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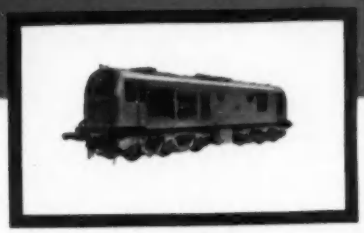

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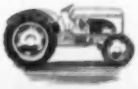

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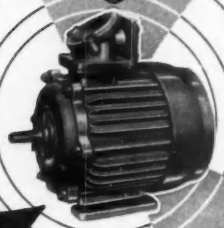

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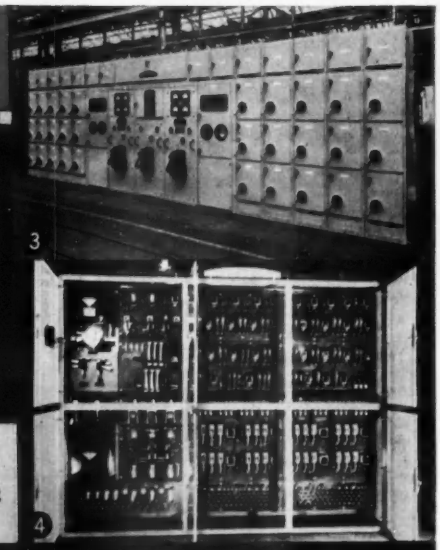

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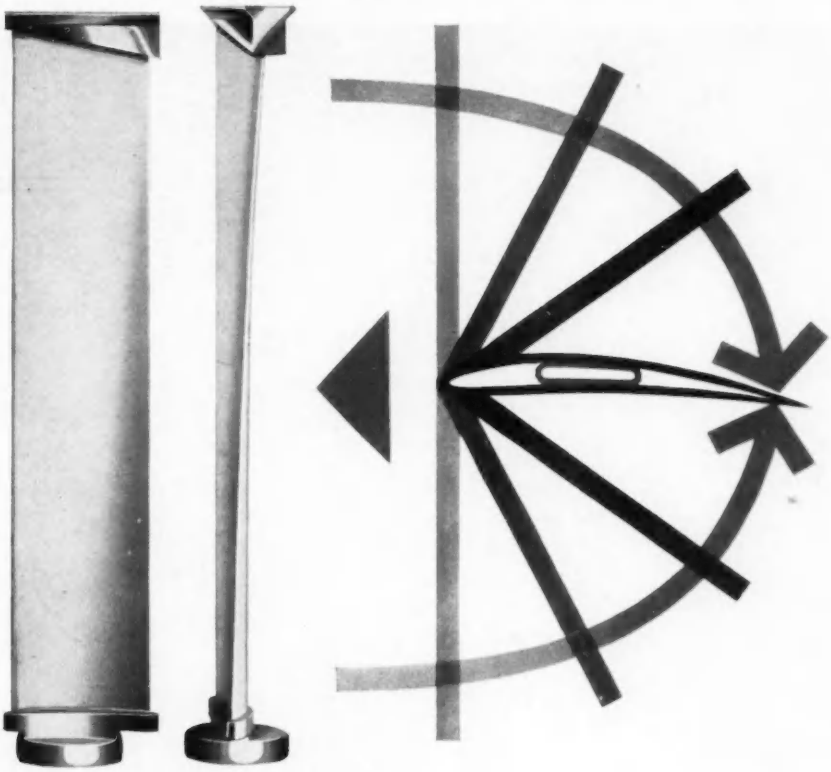

The illustration is shown by courtesy of Armstrong Siddeley Motors Ltd.

A new way with Hollow Blades

Wilmot Breeden, interested in the manipulation of metal in the cold state, have developed in co-operation with famous jet engine firms a new process for the manufacture of inlet guide vanes and stator blades. These envelopes are now formed in nickel-chrome alloys in a succession of press operations from a flat blank, the trailing edge being brazed—in a controlled protective atmosphere—to extremely close tolerances, leaving a minimum of material to be removed and eliminating any risk of weakening the joint.

The inlet guide vanes and stator blades determine the direction of flow of the air entering and passing through the compressor to the combustion chambers. Accuracy of the envelope is vital, particularly so at the trailing edge. The vane is anti-iced by passing hot air through it. This air is distributed by means of one or more perforated ducts, which may form strengthening members, positioned within the envelope. The benefits of this process are: minimum weight for given envelope size, full response to aerofoil requirements, maximum heat transfer because of uniform wall thickness, ease of accommodating end fixings of widely differing design.

The illustration shows an inlet guide vane for a Sapphire engine; the envelope and the single air duct of this blade are of stainless steel as are the spherical end bearing and the dovetail at the root end. Both end fixings are machined and ground to close tolerances after being brazed into position by induction heating.

If you have an application for this new method we should be pleased to investigate and advise.

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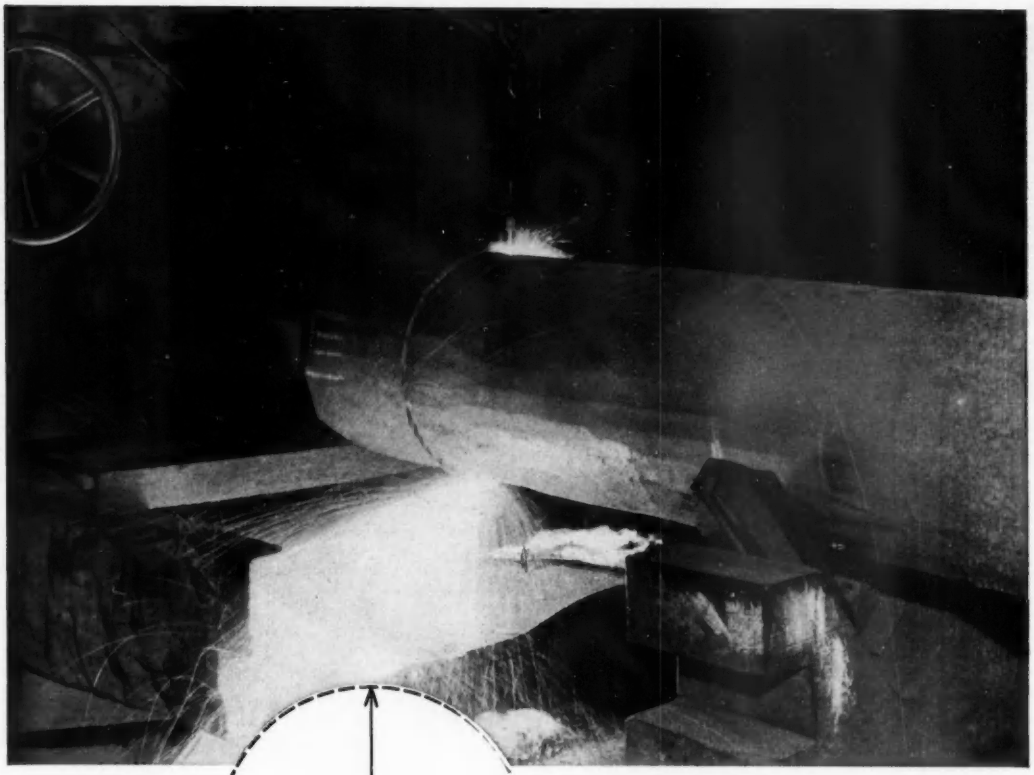

Cutting 22" steel with PYROGAS

This photograph was taken at the Dennystoun Forge, Dumbarton and shows machine cutting of a 22" diameter steel shaft. The fuel gas—Pyrogas, and the B.G.T. cutting nozzle were both supplied by Saturn Industrial Gases Limited.

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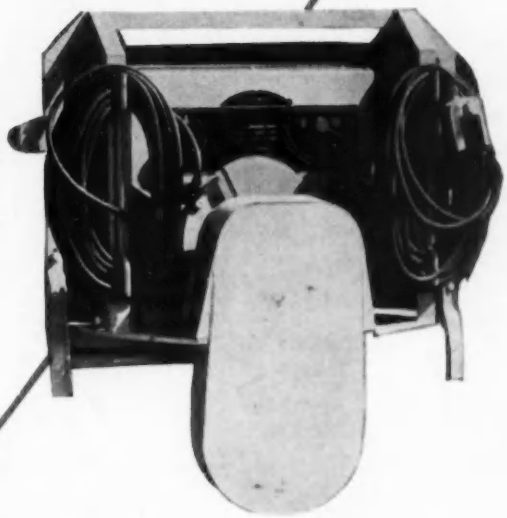

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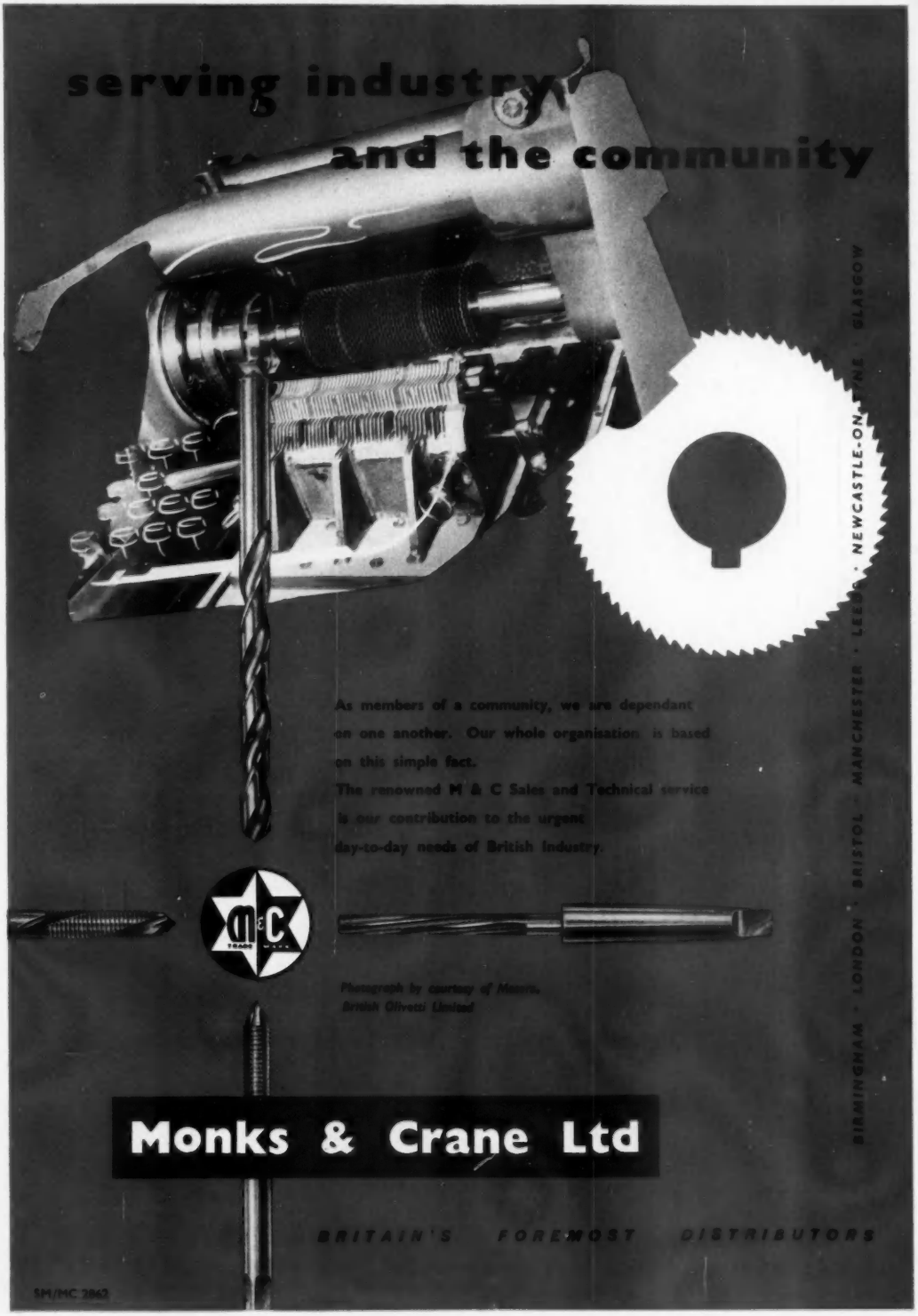
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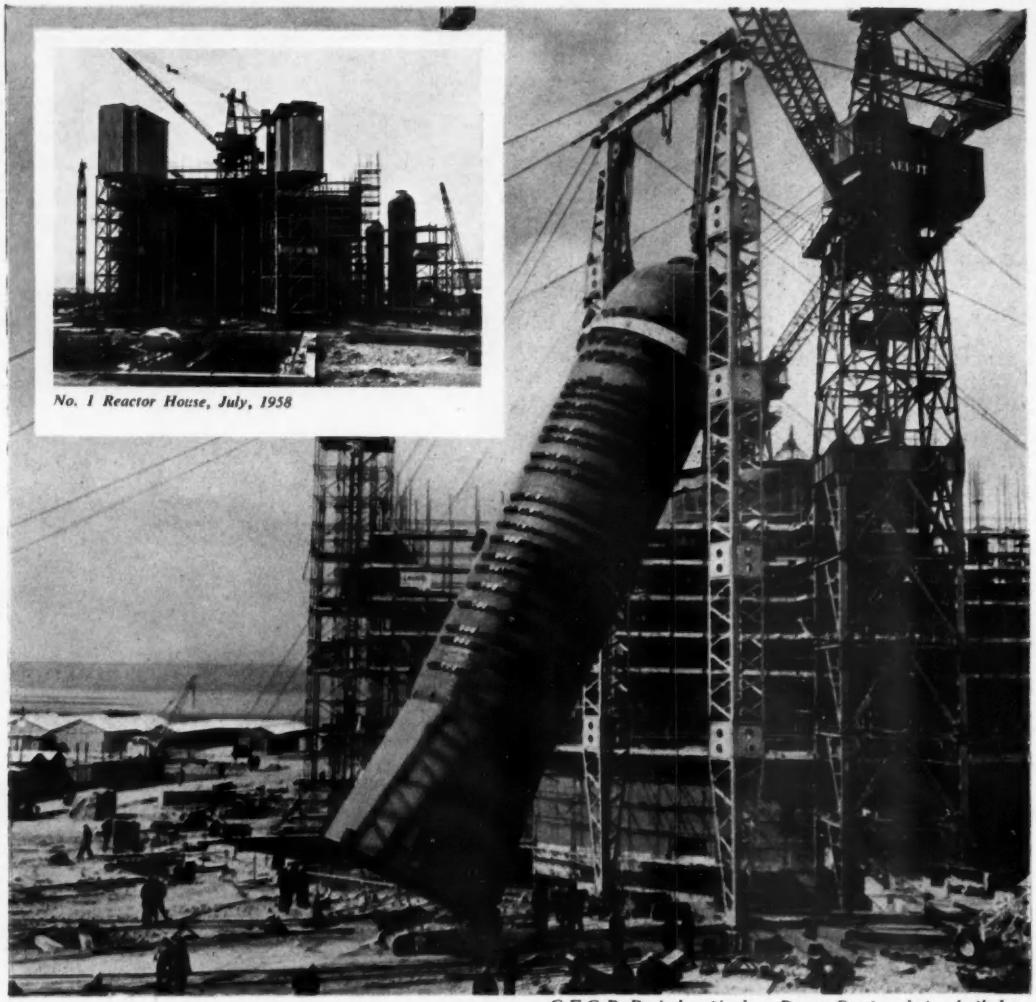

No. 1 Reactor House, July, 1958

C.E.G.B. Berkeley Nuclear Power Station, being built by A.E.I.-John Thompson Nuclear Energy Company Ltd.

HEAT EXCHANGERS, BERKELEY

The sixteen large heat exchanger (or 'boiler') vessels for Berkeley Nuclear Power Station are now being erected on site by John Thompson.

The vessels, 70 ft. long, 17 ft. 6 in. in diameter and weighing 133 tons, are transported on two bogies from the Berkeley site boiler shop, where fabrication is completed, to their positions adjoining the reactor houses.

Manufacture and installation of these heat-exchanger vessels by John Thompson is so arranged to eliminate the transportation of excessive loads from the works at Wolverhampton and yet to reduce to a minimum the amount of work to be done on site. This is achieved by manufacture of the vessel in sections at the home works and then welding-up the sections to form complete vessels in a site boilershop specially erected at Berkeley. The site boilershop accommodates four vessels at a time.

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A19a

THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *SOLID-STATE SWITCHING DEVICE*

A new solid-state switching device adapts the principles of an electrolytic condenser by controlling the dielectric breakdown of an aluminium oxide film deposited on aluminium foil. The new device has the properties of a capacitor with a breakdown voltage of approximately 14 V, a capacitance of 0·0005 microfarad, and a leakage resistance in the kilomegohm range, while its resistance at the critical voltage drops to about 1 ohm. The energy transformation is large and, for voltages which are higher than the critical voltage, the switch units can be stacked. It is reported that switches of this kind with $\frac{1}{4}$-in. diameter electrodes have a capacitance of about 0·002 microfarad and a dissipation factor of 1 to 2%, while those with $\frac{1}{8}$-in. diameter electrodes have a capacitance of 0·0005 microfarad. The average breakdown voltage at —60°C is about 14% higher than at room temperature, and about 16% lower at about 100°C. Breakdown voltage has been found to be practically independent of the rise time of the breakdown pulse for periods longer than about 10 millisec. Breakdown voltages measured with pulses of 1 to 5 microsec are about 80% higher than those observed with pulses which are longer by at least four orders of magnitude. In shock tests, the switch has withstood successfully accelerations of more than 7000 *g*. In radiation tests, a gamma dosage of 6×10^4 roentgens and a neutron dosage of $1{\cdot}6 \times 10^{13}$ neutrons/cm^2 (fission spectrum) have exercised no effect on the breakdown properties of the switch, which is rugged, contains no moving parts, is inexpensive, and is of small dimensions. It is considered that its use should reduce overall volume, as well as power, requirements.

● *SUPERCONDUCTING CONNECTIONS FOR CRYOGENIC CIRCUITS*

Superconducting connections, with zero resistance, are required in cryogenic circuits. A superconductor can be driven into the normal state when the magnetic field of the current passing through it exceeds the critical magnetic field of the metal, and a wire will lose its superconducting properties if it is connected to a film at only one small point. The usual methods of making superconducting electrical connections are not satisfactory when the gate of a cryotron is a film of tin on insulated wire, as flux, heat, or chemical action will destroy the film. It has now been found, however, that satisfactory connections can be made with lead powder of the finest commercial particle size, compressed in a cavity in which the film, on its wire base, is inserted. External leads are usually solder-coated copper wires. In one such method the cavity is filled by heaping with lead powder, which is then compressed with a hand crimper until the lead appears solid, providing a continuous superconducting path between the solder-coated wire and the wire bearing the film. A second method reduces the strain on the film by supporting the wire on a plastic base which remains permanently attached. Powdered lead is put into cavities at the ends of the base, and the wire bearing the film is inserted through slots, external leads being inserted into holes in the front of the base, and a punch operating at a pressure of 5000 psi being used to compress the lead powder. Flexing the base wire can cause the film to fracture. This is a disadvantage with the first method, but not so much with the second. The critical current of an assembly is the current which causes a voltage to disappear across the specimen. In order to test connections, current and voltage leads are attached to the external leads, a voltmeter of 10 microvolts full-scale deflection being used to determine the appearance of voltage across the sample. This lead-powder technique provides critical currents as high as 1 A with films of soft metals such as lead and tin.

● *HIGH-TEMPERATURE STRAIN-GAUGES*

In determining the suitability of structural materials for many high-temperature applications, there is a definite requirement for strain-gauges capable of operation at elevated temperatures. In this connection, it is reported that a strain-gauge giving usable static-strain data at temperatures up to 800°F has now been developed. The new gauge consists of two straight wires, 0·001 in. in diameter and $\frac{3}{4}$ in. in length, welded to narrow strips of Inconel foil, 0·002 in. in thickness. These strips, which form the leads and shunt at the bottom of the gauge, are crimped to a backing of asbestos paper previously coated with a thin layer of ceramic cement. In use, the gauge is cemented to the surface of the test structure with the same ceramic cement, no precoating of the test surface being necessary. As the wet cement does

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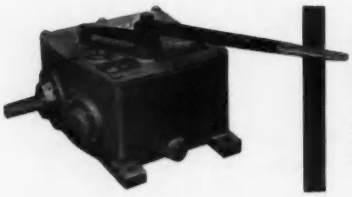

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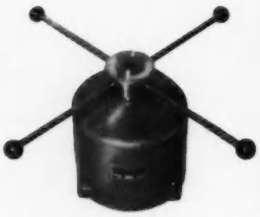

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not completely flow out from under the Inconel strips when the gauge is pressed into position, there is no electrical short-circuiting to earth. Measurements have shown that the filament wires are from 0·001 to 0·002 in. from the test surface after the gauge has been applied. One advantage of the device appears to be that it is completely prefabricated and can therefore be attached to many recessed areas of the test structure. To extend the upper range of temperature, an investigation is being made of cements which show higher electrical resistivity at elevated temperatures, and a cement has recently been developed which has improved properties in the range from 1400 to 1800°F. Ceramic coating of the filament is also being investigated, both for improving the resistance stability of the wire and for assisting the cements to prevent electrical leakage to earth.

● *NEW HARDENABLE TITANIUM ALLOY*

A new titanium alloy, available as sheet or wire, can be formed in the ductile annealed condition and then hardened by simple ageing treatment. Like certain aluminium alloys, stainless steels, and beryllium-copper alloys, the new alloy is precipitation-hardening, and the final combination of strength and ductility is stated to be controllable over a wide range by suitable choice of heat-treating temperature and time. Containing 13% vanadium, 11% chromium, and 3% aluminium, the alloy, in its formable annealed condition, has a yield strength between 120,000 and 135,000 psi, with elongations between 10 and 15%. In the form of rods, it can be cold-headed for rivets, and parts can be brazed or welded. The bend-radius at room temperature can be as low as three times the thickness, and only twice the thickness at temperatures between 200 and 300°F. Hardening is effected by a simple single-temperature heat treatment at from 850 to 900°F in air for from 50 to 100 hr, the heat treatment required to produce the highest strength (240,000 psi, with an elongation of 2%) being 72 hr at 900°F. Dual-temperature heat treatments are now in course of development and indicate that these times will be greatly reduced. Hardening time is only moderately affected by the amount of cold work induced during forming. Hardening proceeds at a varying rate, response (as measured by tensile strength) being slow at first, then increasing fairly rapidly with increasing time, and finally slowing down well before reaching a maximum. Considerable additional time may bring some loss in strength. The time required for reaching the first maximum is not critical, and may vary by 10% or more with little effect. Higher hardening temperatures are stated to yield higher strengths, with shortened heat-treating time, as is characteristic of other precipitation-hardening alloys. Also, ductility is less with heat treatments giving higher strength. An important advantage of the new alloy is its ability to take cold-heading in the soft state and then undergo hardening, thereby making it possible to cold-forge rivets and bolt heads with a large saving in material and machining time.

● *HIGH-TEMPERATURE OSCILLATING-CUP VISCOMETER*

An oscillating-cup type of viscometer is being developed for measuring the viscosity of liquid inorganic oxides at temperatures up to 2000°C or higher, and the feasibility of using this method for measurements in the anticipated viscosity range is said to have been demonstrated with a prototype model. Values of the viscosity of a liquid and its rate of change with temperature find immediate application in fundamental research on molecular structure, and are also of direct use in many technological problems, such as the calculation of forces required for the mechanical transport of a liquid. However, before such data can be obtained for temperatures above 1500°C, the problems confronting nearly all high-temperature measurements must be effectively met, among the more serious being those of corrosion and vaporization. Both these factors produce changes not only in the mass and geometry of the sample, but possibly in its composition as well, while stray vapours can react harmfully with critical parts of the apparatus. Also, for greater dimensional stability and reproducibility, it is desirable that the instrument be of simple shape and construction. The oscillating-cup method fulfils these requirements. The sample liquid is enclosed in a cup which is suspended from a wire to form a torsion pendulum ; when torsional vibrations are initiated, the presence of the liquid causes them to be damped. As the amount of damping depends on viscosity, the latter can be calculated from the observed rate at which the vibrations decay. In the viscometer under development, high temperatures will be produced by induction heating. The cup will be affixed to a rigid rod, which will be suspended from a torsion wire, on which the rod and the cup oscillate as a unit.

● *DETECTION OF OPEN FUSES BY MAGNETIC AMPLIFIERS*

Circuit protection in digital computing systems is of great importance, as undetected loss of a voltage may cause extensive damage to circuit components. The most common methods of circuit protection in complex digital computers are indicator or signalling fuses, resettable indicating fuses, and circuit-breakers, the latter, however, being relatively expensive and seldom rated for high d.c. voltage. Fuses protect

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the circuits, but occasionally fail as indicators, possibly resulting in considerable outage time in a large computing system. A recent report points out that circuit protection at the load centres of a computer system can be accomplished by sensing devices which determine if any fuses are open, in which case the d.c. voltages to the part affected are turned off. In the new system, the sensing of open fuses is accomplished by placing one of the control windings of a series-connected magnetic amplifier across each fuse, with an appropriate current-limiting resistor in series with each winding. If a fuse opens, the voltage drop across the fuse forces current through the control winding, causing the magnetic amplifier to saturate. With the magnetic amplifier saturated, a voltage is applied across a bridge, the output from which operates a relay which opens the relays and contactors switching the d.c. power to the affected piece of equipment. Since speed and size are important, the magnetic amplifier used was made to operate at a frequency of 400 cps. Although a self-saturating type of magnetic amplifier would make the unit more sensitive, it would also be sensitive to the direction of the control current, which in many cases would be unpredictable. The actual operation of this detection system is claimed to have disclosed several useful and unforeseen features. Thus, on several occasions the magnetic amplifier sensed an overload and turned the d.c. voltages off before the fuse could actually clear the condition.

● *IMPROVED HYDRODYNAMIC CLUTCH AND SEPARATOR-CLUTCH COMBINATION*

With conventional combinations of a speed-dependent clutch with a separator clutch automatically actuated by an electrical contact during gear-changing operations, the disadvantages arises that, especially where hydrodynamic clutches are used as motor-speed-dependent starting-away clutches, a drag torque is transmitted when the engine is idling, causing jerking and then creeping of the vehicle when a gear is engaged with the vehicle stationary. Apart from the fact that this phenomenon is unpleasant, the hydrodynamic clutch becomes unnecessarily heated when the engine runs for a relatively long period with the vehicle stationary and the gear engaged. To overcome these disadvantages, a recent proposal is to modify the control-current circuit for actuation of the separator clutch. This circuit is closed when the gear is shifted by a switch installed either in the gear-shift lever or possibly in the gear itself. In the new arrangement, the circuit is additionally closed as soon as engine speed drops below a certain level or when the engine is idling. Admittedly, with such an arrangement, engagement of the clutch, when the vehicle is allowed to roll down a gradient, would take place only after the engine is first accelerated, i.e., after the throttle is opened. To overcome this drawback, the new proposal includes another device actuated by the driven shaft, i.e., the clutch shaft or the gear output shaft) which interrupts the control-current circuit for the clutch as soon as the vehicle is set in motion or exceeds a certain speed.

● *WATER-GLASS COATINGS FOR THE HEAT TREATMENT OF REACTIVE METALS*

Water-glass coatings are claimed to have solved the problem of heat-treating reactive metals, such as titanium and zirconium, by preventing embrittlement and scaling of these materials. When searching for a suitable coating, encouraging results were first obtained with a silicone paint containing aluminium powder. This coating prevented oxidation during heat treatment but, after the materials were quenched, the coatings had to be removed with an alkaline softener and a hydrofluoric acid pickling solution, frequently leading to etching of the metal surfaces themselves. Also, it was found necessary to replace scratched or damaged coatings before heat treatment, because repair was impractical. These disadvantages are not encountered with water glass, which can be sprayed on the surface before heat treatment and allowed to dry in air, preventing oxidation at temperatures as high as 2000°F. The water-glass mixture, which is prepared by adding powdered sodium silicate to a solvent-dispersed resin or binding medium, can be sprayed like lacquer, dries rapidly, and requires no supplemental processing. As a rule, three coatings will protect the metal parts against oxidation, and if a protected part should be scratched before it is heated, the finish can be easily repaired. If necessary, metals can be heat-treated in less than an hour after the coating is applied. Above 300°F white opaque constituents of the coating are burned or vaporized by heat, leaving sodium silicate powder to fuse and protect the metal surface. When removed from a heat-treating furnace, the metals are covered by transparent water-glass alone. The finish cannot be satisfactorily removed with water, but it can be quickly dissolved in a solution of caustic-soda, without any detectable tendency to etch the surfaces.

● *COBALT-COPPER-MANGANESE ALLOYS FOR HARD SOLDERING*

Various solders for steel and hard metals are in use, but, in general, effective results with these solders can be achieved only by sacrificing in some degree one or other of the desirable functions of the solder alloy. In order to overcome these disadvantages, many additional metallic components have been introduced into

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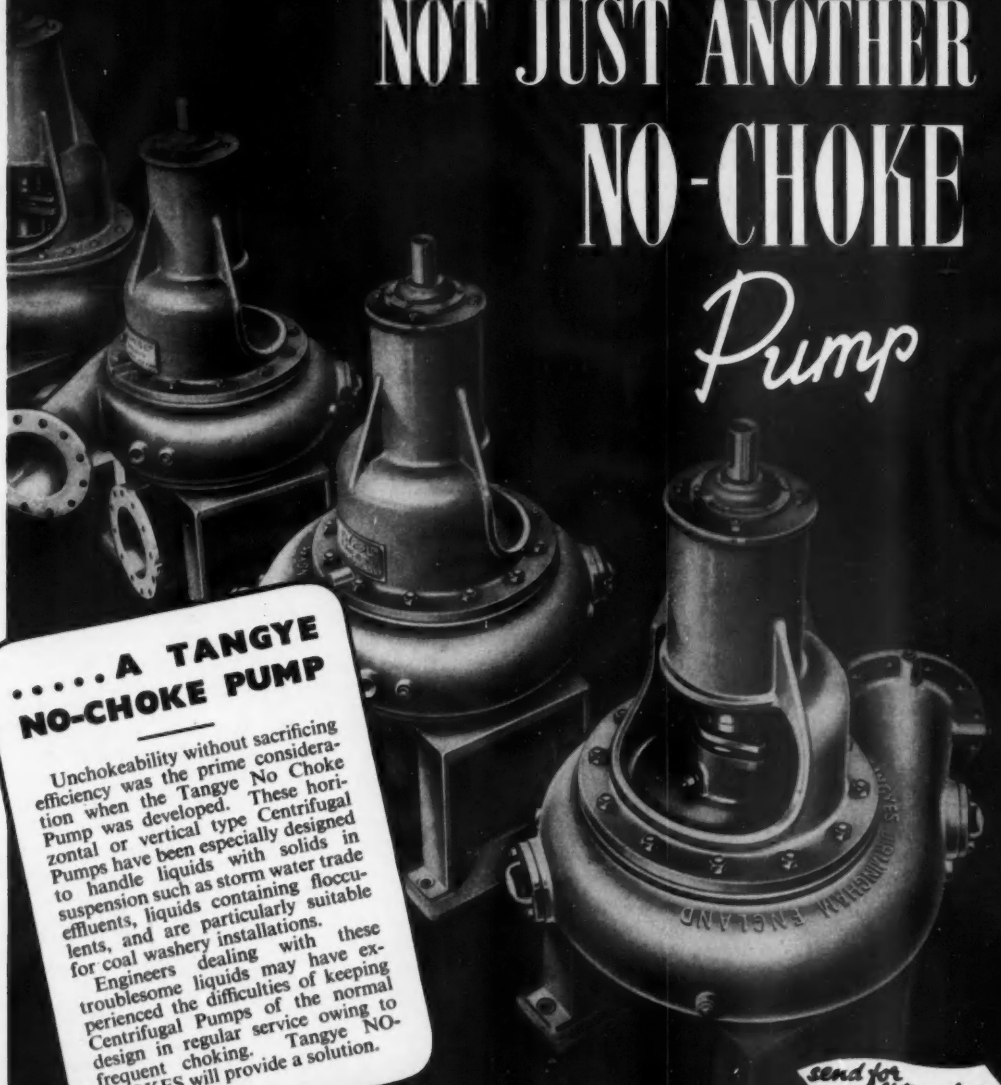

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solder alloys, e.g., for improving flow behaviour and the wetting power. Occasionally, the purpose of these additives is also to lower the working temperature, but in most cases this results in a lowering of heat resistance. It has now surprisingly been found that alloys of the ternary system cobalt-copper-manganese, with from 1 to 10% cobalt, 55 to 95% copper, and 4 to 35% manganese, are eminently suitable as solders for alloyed steels, hard metals, and other materials which are normally difficult to solder. Favourable results are claimed to have been obtained with alloys containing from 2·5 to 7·5% Co, 70 to 90% Cu, and 5 to 25% Mn, while alloys with from 2·5 to 6% Co, 80 to 90% Cu, and 7·5 to 15% Mn have proved especially satisfactory. It is stated that these alloys have a substantially more favourable behaviour than previously known steel and hard-metal solders, as regards working temperature and flowing power, while the soldered seam shows a surprisingly high strength value. It is also stated that the melting range of the alloys is narrow, so that they show no tendency to form shrinkage cavities when used as solders. Moreover, they have excellent toughness, as well as a sufficient degree of hardness, and possess good wetting power. In addition, these alloys, which have working temperatures ranging between about 900 and 1050°C, can be rolled and drawn satisfactorily in the cold state, and, if desired, can be subjected to a final hardening treatment.

● *IMPROVING THE SERVICE LIFE OF HYDRAULIC TUBING*

A recent paper points out that designers of hydraulic systems should pay more attention to the causes of fatigue failure of hydraulic tubing, particularly of the type used in aircraft. One of the chronic troubles of such systems is the development of pin-hole leaks, which have been identified as tiny cracks produced by internal pressure fluctuations. These failures almost invariably occur in locations where the tubing has been deformed by bending and has therefore been slightly flattened. Owing to the "breathing" of the flattened section, high circumferential stresses occur at certain locations in the bend, and cracks will therefore usually start at these points of highest stress concentration. It is interesting to note that the surface roughness of the tubing, particularly at the inside surface, also affects the fatigue life of the tubing. Rough surfaces have lower fatigue lives than smooth surfaces, while tubes with deep, sharp seams or intergranular corrosion have the lowest fatigue life of all. Obviously, in a rough surface, a stress-concentration effect, similar to a notch effect in fatigue, is present, and this effect is a function of the relative depth and sharpness of the notch, which is generally expressed by the radius of curvature at its base. However, the notches or seams inherent in the rough surface in the tubing are very irregular in shape, and the radius of the curvature is very difficult to measure. Consequently, the "included-angle" at the notch bottom has been proposed as an index of sharpness. Test results have proved that fatigue life rises when this angle becomes more obtuse. Unfortunately, the depth and sharpness of shallow flaws cannot as yet be determined non-destructively.

● *MEASUREMENT OF THE ELASTIC MODULUS OF PLASTICS AT HIGH TEMPERATURES*

In research conducted to synthesize plastic materials satisfactory for use at high temperatures, a test method is required for the rapid determination of the heat resistance of newly synthesized materials and for the collection of data relating the properties of these materials to their composition. Such a test method must be suitable for conducting tests at elevated temperatures with controlled atmospheres, which may be oxidizing or non-oxidizing, and must also be capable of examining the small amounts of materials which are typical of production on the research scale. It is reported that a simple and inexpensive test instrument, called an elastometer, has now been devised to meet these requirements. In this instrument, a reed, composed of the sample material, is held at one end in a clamp and is caused to vibrate by a rod pressing on the reed near the clamp. The frequency of vibration at maximum amplitude is observed visually and is used in the calculation of the elastic modulus. The device is so constructed that specimens can be surrounded with inert or oxidizing atmospheres from room temperature to 1100°F. The specimen clamp is located near the centre of a heat-resistant glass tube, in which the temperature may be suitably controlled, and it is possible to maintain a vacuum or an atmosphere of any desired gas by the use of inlet and outlet tubes. The specimen is observed through a glass window at one end of the glass tube, and is caused to vibrate by means of a rod which extends through a metal bellows attached to a side arm of the elastometer tube. This rod is agitated by a transducer, which is operated by a variable-frequency generator amplifier. The specimen-clamp assembly can be moved in an axial direction through the tube by turning a knob outside the tube at one end. Thus, the point of contact between the driving rod and the specimen may be changed. Thermocouples are mounted at various points near the specimen on the interior wall of the glass tube, and it has also been found possible to locate a thermocouple between the clamp and the reed, without affecting the vibrational properties of the reed.

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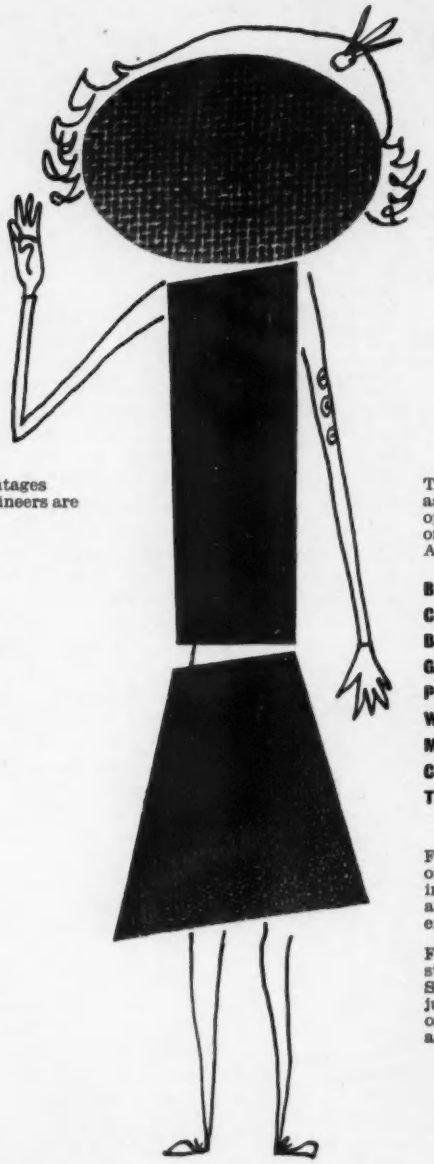

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(Part I)

BY

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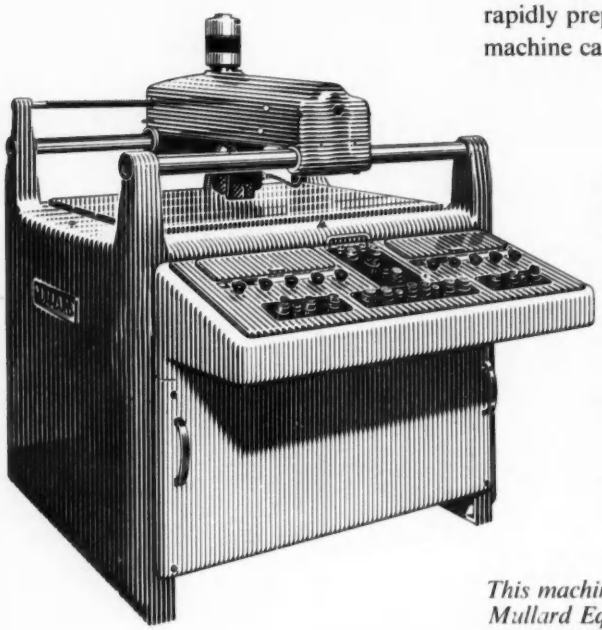

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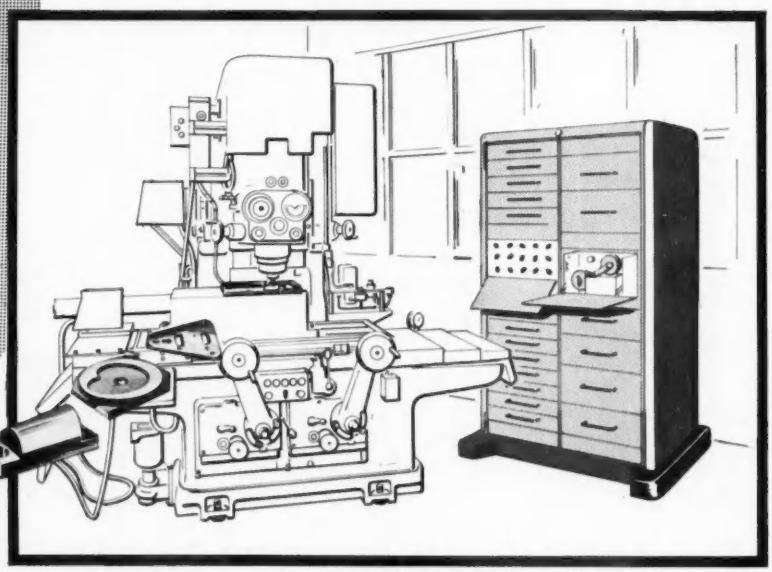

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The Numerical Control of Machine Tools

By R. C. Brewer*

Introduction

Until a few years ago, the word "automatic", with regard to machine tools, normally meant control either by cams or by a tracer mechanism and master profile. The introduction of this type of operation had two advantages, i.e., (1) many components, hitherto almost impossible to produce, could now be made with little difficulty, and (2) a large range of components could be produced more economically under certain circumstances very largely connected (a) with the manufacture of cams or master profiles, and (b) set-up time. The manufacture of cams or master profiles represented not only a considerable time delay but also a very heavy cost, which had to be shared between all components to be produced. Set-up time, which could involve several hours work by skilled personnel, was also costly and, in this case, could be shared between the components produced in that particular batch only.

Thus, the circumstances which dictated any form of automatic working were largely associated with the number of components required and, although quite a considerable amount of thought has been devoted to the use of "automatics" in small-number production, it is still largely true to say that automatic operation of this kind is associated with large numbers of components.

In the early post-war years, some development work was done on the "playback" system of automatic machining. This system required the services of a skilled operator who carefully produced one component, the operations performed being recorded on magnetic tape, which could be played back for producing further components. In essentials, the system usually consisted of a contact arm, mounted on the leadscrew, this contact moving over a commutator or contact ring. In one system, successive contacts were supplied with electrical voltages of different frequencies, and thus the rate at which the frequencies changed on the magnetic tape was proportional to the speed with which the contact moved over the commutator, i.e., the speed at which the table moved.

When the tape was played back, electrical relay circuits operated a motor whose speed was dictated by the rate of change of frequencies on the tape ; the direction of rotation of the motor was governed by the sequence of the frequencies, this sequence, of course, depending on the direction in which the table was moved when the recording was made. By coupling this motor to the leadscrew of the machine, the original movements of the operator could be repeated. While having certain advantages, this system is still dependent on the accuracy with which a human operator can work. For straight lines parallel to one of the machine axes, this is reasonably high but, for other straight lines and curves, particularly in three dimensions, human operation leaves much to be desired.

There is, of course, some advantage to be gained by what might be called a "time-magnification effect", i.e., the effect obtained when recording and playback speeds differ, thus enabling the component to be produced at the desired feed rate and giving the operator more time to work accurately ; this time magnification, however, cannot be increased indefinitely, and a point is soon reached at which the operator is unable to work with the required accuracy, unless the feed rate is reduced considerably below an economic value.

One interesting departure from the sequential frequency technique is that used by the Micropositioner Division of Topp Industries Inc.; in this technique, a steel tape, $\frac{3}{4}$ in. wide, is stretched along each axis to be controlled and, at the relevant points when the operator has positioned the table, a power-operated punch makes a conical indentation in the tape. During playback, a precision switch pre-senses this indentation and causes a rapid deceleration, whilst a second switch then senses the indentation and controls the final positioning.

The deficiencies of human response were felt several years ago in other fields, e.g., gunnery and the control of chemical processes, and led to the introduction of the concept of automatic control. Control systems, often called servo-mechanisms in engineering, were developed to eliminate human control. Automatic control and the more advanced mechanization techniques are frequently referred to as automation. Undoubtedly, they both contribute to automatic operation, but only automatic control makes any attempt to emulate the human brain, at least to the extent that it can be so arranged as to discern when a process is not doing what it should and then to take corrective action ; in other words, it does nothing to the system until the system ceases to function correctly and hence it is often called an error-actuated system.

In producing a component on a machine tool, the operations may be "programmed", i.e., the paths to be taken by the tool and the rate at which they are taken, may be determined. An automatic control system could then be used to keep a continuous check on the location of the tool and to take corrective action as the need arose. It is of importance to note that such a system will not prevent the tool deviating from the correct path, but will only bring it back to the desired path when it has deviated. Thus, a servo-mechanism has, inherently, a delay or reaction time, which, however, can be made considerably less than that of a human operator.

The main object of this survey is to consider how the principles of automatic control may be applied to machine tools, so as to eliminate human operators partially or entirely. There is a certain amount of literature on the subject but, almost invariably, there has been no attempt to elucidate the terminology or philosophy of automatic control ; consequently, descriptions are only partly understood by production engineers, who have to assess, buy, and operate these automatically controlled machine tools. This has been borne in mind in preparing this survey, which it is hoped will form a more or less complete description of this new concept.

* The Imperial College of Science and Technology, London.

The Basic Philosophy

The geometric form of any component to be produced may be specified by means of numbers ; thus, the conventional dimensioned engineering drawing is really a graphical method of associating the concrete form of the component with the numbers which specify its form. As an aid to the designer, the drawing is often invaluable and is unlikely to become outdated. For purposes of production, however, slides, tables, etc. have to be moved through certain distances in definite directions, and the prime requirement is for numerical information in the most suitable form, usually by means of co-ordinates with respect to either polar or rectangular (Cartesian) axes. However, as Fig. 1 indicates, other sources of information exist.

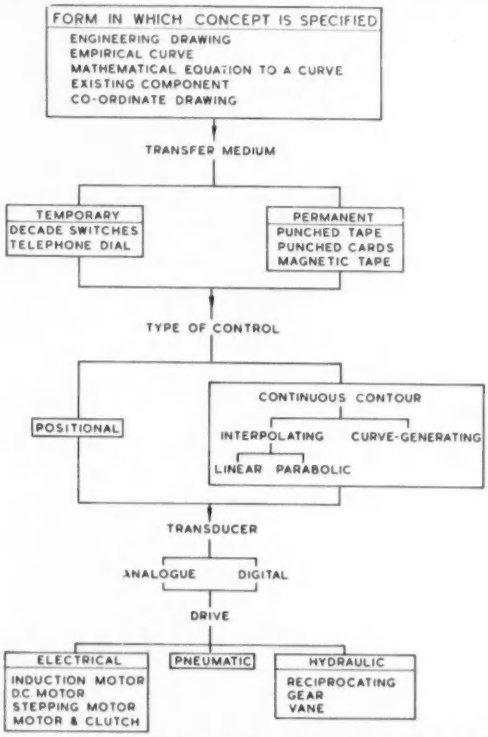

Fig. 1. Basic concept of the stages involved in the numerical control of machine tools.

If the operator is to be eliminated, then this numerical information must be fed to the machine tool automatically by some electrical or mechanical means. It is from this concept that the term " numerical control " has been derived.

Consider the most general problem, i.e., that of making a table move from one position *A* to another position *B* along some specified path. The stages in accomplishing this movement are :—

(1) When the original form in which the component was specified has been converted to a suitable numerical form, it passes through a transfer medium, such as a manual punch, teletypewriter, or a set of decade switches. The two former methods produce permanent storage media (punched cards or a punched tape), while decade switches merely make a temporary conversion from conventional numerical language into electrical or electronic form. A decade switch is merely a 10-way switch in which each contact corresponds to the decade of numbers 0, 1, 2, 3 . . . 9, which is the basis of the decimal system of counting. As yet, the use of magnetic tape at this stage of the control system is comparatively rare, although it is almost invariably used later in the system as the output from the computer, should the system require one.

(2) To specify the desired path from *A* to *B* with sufficient accuracy requires the determination of a number of intermediate points, which may be found tediously by arithmetic, or by some form of computer.

(3) All this information must now be fed to the unit controlling the machine tool. This is usually effected by punched cards, punched tape, or magnetic tape. The control unit then causes the table to move.

(4) In order to know whether the table is moving as it should, a measuring device is needed to determine its position, which is then compared with the position it should occupy.

(5) Should there be any error in the position of the table, an error signal is needed to operate the motor and hence to bring the table to its required position. This type of system is referred to as a feedback loop, since the information about the table position is fed back to the control unit.

It should be realized that one or more of the stages may be eliminated, e.g., if the table has to move from an initial position *A* to a final position *B*, the path being unimportant, then stage (2) is not required. These stages will now be discussed at rather greater length.

(1) Numerical Coding and Storage

By numerical coding and storage is meant the operation of transferring the numbers on the drawing into a form suitable for feeding to a mechanical, as distinct from a human, operator. It is also desirable, perhaps even essential, that this be done in a form which acts as a permanent storage for such information.

Those not familiar with electronic computation and its related problems are probably accustomed to counting numbers in the decimal system only. This system uses ten quite distinct marks or symbols from zero up to the number denoted by 9, these symbols being, of course, the " units ". When 9 is reached, the use of different symbols ceases and the next number, 10, is denoted by two symbols already used. The significance of the " 1 " written in the second place (from the right) is that counting is now being done in " tens " instead of units. Evidently, this procedure repeats indefinitely in both directions, so that, as an example, the number 17·865 really means

$$(1 \times 10^{1}) + (7 \times 10^{0}) + (8 \times 10^{-1}) + (6 \times 10^{-2}) + (5 \times 10^{-3}).$$

It is an argument with some conviction that the decimal system is connected with the number of fingers and thumbs on man's two hands, but the chief point of interest here is that the use of 10 as the basis of counting is quite arbitrary. Other numerical systems have been suggested from time to time, particularly 12 (the duodecimal system) and 8 (the octenary system). If electrical circuitry is to be used in counting devices, two possibilities suggest themselves. For example, the number 7 may be represented either by an electrical signal* which is distinctive to the number 7, or seven electrical signals of

* " Signal " is a generic term covering electrical quantities in general and may be a voltage, frequency, etc.

short duration may be repeated in rapid succession. These latter signals are called " puises " and, as an example, are generated in a telephone dial system each time the dial returns to its position of rest ; indeed, the the telephone dial has been used as one method of translating numbers into electrical form for numerical control purposes.

The former suggestion that a signal distinctive to " 7 " be provided does not appear to be so easy to apply, since seven different kinds of signal would be required. However, if the decimal system of counting is abandoned and replaced by one which repeats not at powers of ten but at powers of two (2, $2^2 = 4$, $2^3 = 8$, etc.) only two distinctive signals are needed, i.e., for 1 and 0. This is a considerable simplification from the electrical point of view and could be provided in many ways, e.g., by polarizing a voltage (positive or negative), by the operation of a simple on-off switch, or indeed by anything characterized by two distinct states. For high-speed computing, electronic means must be sought, and a very convenient device is one which is very picturesquely known as a "flip-flop ". This is a pair of electronic valves, coupled together so that only one is conducting at once and, as it ceases to conduct, it automatically causes the other to begin to conduct, this alternation being the origin of the term flip-flop.

This sytem of counting in powers of two is called the binary system and, for those who are not familiar with systems of counting other than the decimal system, a short digression will be made at this juncture. The binary numbers 0 and 1 are the same as the decimal numbers 0 and 1, but the binary system has now exhausted its two distinct symbols and is forced to move to a new place, i.e., the second place, for the equivalent of the decimal number 2, which in binary form is thus written 10*. It should be noted that the binary system has been forced to adopt a second place, i.e., to become a " two-figure number " for its third figure, whereas the decimal system avoids this until its eleventh number. Thus, the decimal number 3 is written in binary form as 11, while the decimal number 4 becomes 100 in its binary equivalent.

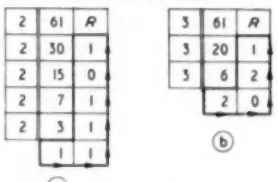

Fig. 2. **Method of converting the number 61 in the decimal code into (a) the binary code, and (b) the ternary code.**

As a matter of fact, transposition of a number in the decimal system to its corresponding number in any other system is an easy matter, all that is required being to divide the decimal number successively by the desired system number as far as possible. The final quotient and the remainders *R* give the required number, as shown in Fig. 2, which shows the decimal number 61 transposed into the binary and ternary systems, the respective results being, as indicated by the arrows, 111101 (Fig. 2a) and 2021 (Fig. 2b). For convenience, however, the binary equivalents of all numbers from 0 to 20 in the decimal system are given in Table I.

* Since the " words " for numbers, e.g., six, twenty-one, etc., are based on decimal conceptions, it is preferable not to use them when reading binary numbers, but to employ the same system as used in reading the figures after the decimal point ; thus binary 10 is read " one-nought " and, in this way, confusion with decimal 10 is avoided.

TABLE I : BINARY EQUIVALENTS OF DECIMAL NUMBERS FROM 0 TO 20.

Decimal	Binary	Decimal	Binary	Decimal	Binary
0	0	7	111	14	1110
1	1	8	1000	15	1111
2	10	9	1001	16	10000
3	11	10	1010	17	10001
4	100	11	1011	18	10010
5	101	12	1100	19	10011
6	110	13	1101	20	10100

It has already been mentioned that, in the decimal system, units are in powers of 10. Thus, a number composed of the digits *abc* can be expressed as $10^2a + 10^1b + 10^0c$. Similarly, then, 111101 in the binary system represents

$$(1 \times 2^5) + (1 \times 2^4) + (1 \times 2^3) + (1 \times 2^2) + (0 \times 2^1) + (1 \times 2^0) = 32 + 16 + 8 + 4 + 0 + 1 = 61.$$

In the same way, 2021 in the ternary system represents

$$(2 \times 3^3) + (0 \times 3^2) + (2 \times 3^1) + (1 \times 3^0) = 54 + 0 + 6 + 1 = 61.$$

Consequently, transposition of any number in a given system back to the decimal system is also an easy matter.

It has been seen that all binary numbers greater than unity require more places than their decimal equivalents and it might be reasonably asked whether, therefore, the binary system enjoys any advantage. To answer this, suppose that a punched tape is used as the storage medium. The most obvious procedure is to allocate for each place in the largest number to be coded a row, in which holes may be punched, as required. These rows are usually referred to as channels, and most tapes have either 5, 6, 8, 12, 14, or 32 channels, the 8-channel tape being the most common for numerical control of machine tools. If numbers from 1 to 99 have to be coded, then the decimal system requires only two places or channels (tens and units), whereas the binary system calls for seven places, since 99 is greater than $2^6 = 64$ and less than $2^7 = 128$. It should be noted, however, that the full information is conveyed in binary coding by one line of seven holes, whereas decimal coding requires either two lines of 10-channel tape or ten lines of 2-channel tape, i.e., twenty holes.

The number of channels required for the binary system could be reduced by a modified binary coding, in which combinations of holes are used to code a given number. Thus, Fig. 3a shows what is termed a 3-out-of-6 binary code, in which each digit must be expressed in terms of three holes out of the total of six channels used. It will be noted that two of these channels are assigned a value of zero, and, as shown in Fig. 3b, which is the code for Fig. 3a, any digit can be expressed in the binary code by three channels, using zeros, where necessary. Thus, $4 = 2^2 + 0 + 0$, $5 = 2^2 + 1 + 0$, etc. It should be noted that the value of 0 must also use three holes, and these can be chosen arbitrarily, provided that they do not coincide with any combination already used for expressing digits from 1 to 9. In the example given in Fig. 3b, although the value of 0 appears to be 6, it is, in fact, distinguished from the actual value assigned to 6 in that the lower, instead of the upper, zero is chosen.

Alternatively, use can be made of binary-decimal coding, as shown in Fig. 3c. This code still counts in decades, like the decimal system, but, within one decade the digits are expressed in binary form. The object of the binary-decimal code, like that of the 3 out-of-6-binary code, is to reduce the number of channels which are required with a conventional pure binary code (Fig. 3e).

Fig. 3d shows decimal coding along the tape and

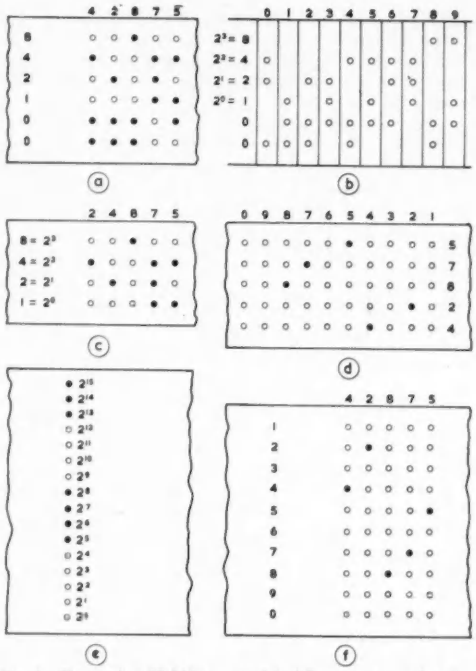

Fig. 3. **The number 57,824 expressed in different systems of coding.** Solid dots represent punched holes.

requires the same number of channels as the number of digits to be expressed, while Fig. 3f shows decimal coding across the tape and requires ten channels. It should be appreciated that, although decimal coding has the advantage of enabling operators to read the tape easily, it requires more holes than pure or modified binary coding systems. Table II compares various media from the point of view of cost and storage capacity.

TABLE II : COMPARATIVE STORAGE COST AND CAPACITY OF VARIOUS MEDIA.

Storage Medium	Digits per unit of cost	Digits per cubic inch
Electromechanical or electronic relays	0·2 to 1	0·2
Punched cards	$2·5 \times 10^3$	$5·0 \times 10^3$
Punched tape (sensed mechanically or optically)	$3·0 \times 10^6$	$1·8 \times 10^4$
35-mm film (mechanically punched and read optically at 10 fps)	$6·0 \times 10^4$	$1·8 \times 10^4$
Wide punched tape (mechanically punched and read optically at 10 fps)	$1·0 \times 10^5$	$1·2 \times 10^4$
35-mm film (optical sensing of 0·01 to 0·02 in. spots)	$1·0 \times 10^6$	$6·0 \times 10^5$
Magnetic wire	$2·5 \times 10^6$	$6·0 \times 10^6$
Magnetic tape	$1·0 \times 10^8$	$2·0 \times 10^6$

In many practical applications, certain permutations of holes which have no numerical significance are reserved for physical instructions to the machine, relating, for instance, to the supply of cutting fluid, changing of tools, etc. These instructions to the machine are referred to as commands by electronics engineers and, in this survey, as functional commands.

When the numerical information is to be stored permanently, punched cards or punched tape of strong paper or plastic material are generally used. The coding and punching is normally carried out on one of the standard telecommunication or business-machine coders, such as a teleprinter, Flexowriter, etc., although some manufacturers have either adapted existing coders or developed new ones. To express the form of the component numerically, the conventional system of dimensioning the engineering drawing must be replaced by a system in which every point of interest is given in co-ordinates with reference to some datum or origin. Whether this be done in rectangular or polar co-ordinates is usually dictated by the way in which the machine element moves ; for example, a milling-machine table has a linear movement in three directions at right angles and obviously calls for the use of rectangular co-ordinates, whilst a cam-milling machine, which operates on the principle of variation in radius with angular rotation, uses polar co-ordinates.

In both these systems, there are two co-ordinates for each point, and thus the procedure of putting the information onto a tape or punched card is the same. Systems which provide for moving from one point to another only, i.e., they are not required to move in any special way between these points, often provide the additional facility of manual setting, providing temporary and permanent storage. For setting manually, a row of five, six, or seven rotary decade switches is provided, the number being set (in decimal form) by adjusting each switch to the desired figure. Although quicker than manual positioning, it will be evident that this alternative method loses two very important advantages of automatic control, these being speed and less risk of erroneous setting. Nevertheless, it is a useful feature on occasions.

The information from the tape has now to be read. A tape-reader normally takes one of two forms—electro-mechanical or optical ; in neither form does the tape pass through the reader with continuous motion, but stops periodically to enable a " block " of information to be read. A block of information may be only one digit, one co-ordinate (Fig. 3d), all the co-ordinates specifying one point, or the co-ordinates for several points. In the electro-mechanical type of reader, a number of spring-loaded pins bears against the tape as it passes through the guide in the tape-reader ; when the tape stops, any pin coinciding with a hole in the tape is enabled to pass through it and hence to make an electrical contact. In the optical system, the pins are replaced by light beams which operate photo-cells or photo-transistors ; the lower inertia of the optical system makes it considerably quicker in reading. This point is of great practical importance, since, in the trend towards higher operating speeds, the reading speed of the tape-reader is usually the limiting factor.

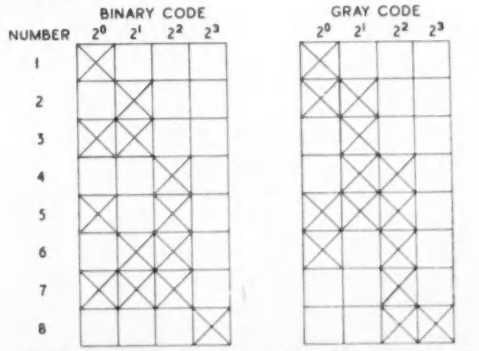

Fig. 4. **The numbers from 1 to 8 expressed in pure binary and in Gray (or cyclic) binary coding.**

Some readers assimilate all the information in one block simultaneously, whilst others read it digit by digit, in which case the earlier digits have to be stored while the latter digits are being read. Usually, relays or switches are used for this purpose and are referred to, collectively, as buffer storage.

One disadvantage of the pure binary code is that, when passing from one number to the next, the digits change in more than one channel and, if the changes in all channels are not read exactly at the same time, a faulty reading of the new number can occur. Special non-simultaneous methods of reading can be devised to overcome this possible ambiguity, but one simple way is to modify the code so that only one digit changes at a time. One such code is the Gray or cyclic binary code, which is illustrated in Fig. 4b and compared with the ordinary binary code in Fig. 4a.

(2) Specification of the Desired Path between Two Points

At this juncture, it is necessary to amplify a basic difference in numerical control systems mentioned briefly in the last section. Any numerical control system is intended to do one of two things, and this affords a convenient means of initial classification ; thus, it may either move the table (or cutter head) through a number of discrete positions, the path followed between these positions being immaterial, or it may effect a continuous control on the path of the moving member. The former type of control is usually termed positional control, whilst the latter is known as continuous contour control.

Although positional control has its own problems, particularly those associated with low-speed friction effects, it is simpler in conception and, the intermediate paths being unimportant, there is no need to specify them. Thus, the considerations of this section are relevant to continuous contour control only.

There are, at the moment, two approaches to the problem of making the moving member follow a specified contour to some required accuracy :—

(a) To abandon any attempt to follow the actual contour and to approximate to it by a series of short chords or tangents passing through calculated points on the curve. This is known as interpolation and, if the short chords are straight lines, the system is called a linear (or straight-line) interpolating system, whilst, if the chords are parabolas, it is known as a parabolic interpolating system ;

(b) To generate a curve which approximates to the required curve to any desired degree of refinement. This is achieved in practice by means of a computer and is called a curve-generating system.

As computers are a feature of most continuous contour control systems, it seems apposite to elaborate a little on the two types of computer. Computers are classified as either digital or analogue. As its name suggests, a digital computer performs its function with numbers expressed in the form of digits. Although not comparable in complexity with a modern machine, an abacus or counting frame is a digital computer and exemplifies its main characteristics. Each bead represents an order of digit, e.g., tens, units, tenths, etc., and the bead is an indivisible unit, i.e., the beads representing the units cannot express in any approximate way the tenths, as this would require a further row of beads. The same holds with the modern digital computer, which has a precision dependent on the number of digits which it is designed to handle ; this, however, is not a weakness, since it means that any required degree of precision can be realized merely by extending the number of digits which it can handle. Obviously, any increase in precision is accompanied by an increase in cost.

An analogue computer is one in which the numbers with which the computation is to be performed are expressed by an analogy; for example, a linear displacement may be represented by a voltage, an electrical capacity, an angular displacement, etc. Analogue computers employing electrical analogies or analogues have such a great versatility that their use is extremely widespread. The precision of an analogue computer is dependent on (1) the inherent precision of which it is capable, and (2) the precision with which it can be operated. A slide-rule is one of the simplest analogue computers with which the engineer is familiar, the numbers to be computed being expressed, via their logarithms, as lengths which are then added or subtracted. The slide-rule has an inherent precision dependent on the accuracy with which it is divided, and also a precision with which it can be read, mainly dependent on its size.

The work of generating a curve for a curve-generating system virtually necessitates the use of a digital computer. For other continuous control systems, the question of computers is more flexible, and at least one commercial system does not use a computer in the strict sense of the word. The use, or otherwise, of any kind of computer is affected by the system to be controlled and by economics. Assuming the availability of a drawing suitable for numerical control purposes, certain calculations must be carried out. These could be performed entirely by human means, but the drawbacks are obviously quite considerable, when the volume of calculations is borne in mind. The simplest mechanical means of assistance is the hand-operated desk calculator, which is considerably slower than a digital computer in operation but, on the other hand, considerably less expensive. A parabolic interpolating system enables a second-order curve (such as an ellipse, circle, parabola, or hyperbola, in which the second power of the variable occurs) to be approximated for some specified tolerance with less points than is possible with a linear interpolating system, and hence the use of a hand-operated desk calculator with a parabolic interpolating system may be considered reasonable, though it

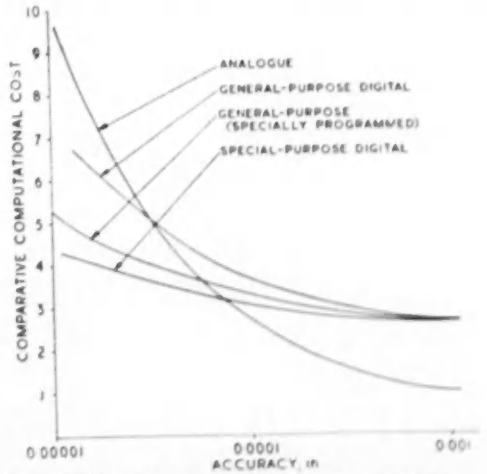

Fig. 5. Variation in the cost of computing as a function of accuracy, for different types of computer.

is doubtful whether a linear interpolating system could be considered without a digital computer. Certainly, all linear interpolating systems at present make use of a computer.

Digital computers are used for a wide variety of operations and, like machine tools, they may be either of general- or special-purpose types. The chief advantage of the special-purpose computer is that its circuitry may be arranged so as best to suit the kind of calculation to be performed. This means that the special-purpose computer operates much faster than a general-purpose computer and more economically, if it can be utilized fully. The economic advantage is greater when higher accuracies are called for, because it is here that the general-purpose computer feels its limitations more acutely, and this is reflected by a greater increase in computational cost than that pertaining to a special-purpose computer. Fig. 5 gives some idea of how computing cost varies with accuracy for different types of computer.

On the other hand, a general-purpose computer may be used for other computations in a medium- to large-size factory for payroll and costing calculations, for example. In aircraft factories it is becoming increasingly safe to assume that a general-purpose computer will be available. It is thus seen that the question of computers is not easy to decide and, furthermore, it is difficult for the control-system manufacturer to give general advice, since factors other than the system may affect the decision. As sums amounting to tens of thousands of pounds may be involved, it may well be that the advice of operations-research consultants should be sought.

It should be pointed out that, as the computational costs are shared between the components to be produced, the problem of the method of computation is serious for small batches, while for larger batches rational consideration of the question could involve the expenditure of more money than it saved. A point which might have influence with some companies is the ease with which modifications can be made. Since the output from most computers is magnetic tape, some advantage could be claimed here for a system which either did not have a computer or whose computer gave a punched-tape output. This could, however, be a double-edged advantage and is typical of the problems involved in this section dealing with the computer, insofar as too many variables and too many circumstances have to be considered. Again, the operational-research approach might be recommended, but, once an optimum decision is made, it would have to be accepted that, on occasions, this decision might turn out to be a bad one, as there is no solution which answers every situation perfectly. Since positional control systems do not involve path computations, users of such systems, when selecting a continuous contour system, must pay as much cognizance to the problems mentioned above as those who have no experience whatever of numerical control.

For smaller companies, or those not requiring numerically controlled machine tools to any great extent, the cost of any kind of computer, general- or special-purpose, will be excessive. A possible solution here is to buy time from a computer centre, although there has been certain criticism of this practice on the score that manufacturing details are passing outside the factory.

The transfer medium from the computer to the machine control unit is invariably permanent and is frequently magnetic tape, the chief advantages of which are (1) the greater rate at which information can be recorded on the tape, and (2) the much shorter length of tape required to record the same amount of information. If punched tape were used as the output from the computer, there would be a greater likelihood that the limiting factor in the speed of transferring information was the tape and not the computer ; this is obviously not desirable.

(3) Table Movement

Moving the table calls for a power source, as with any machine tool, but, in the case of numerical control, the motor must have special characteristics in order to respond adequately to the servo-system. Hydraulic, electrical, and pneumatic drives have been used, but only the first two have achieved any great popularity, possibly because of the stability problems which are usually encountered when pneumatic units are used in servo-systems.

Hydraulic motors have the advantages of a high power/inertia ratio and a high power/volume ratio, these advantages increasing with the supply pressure up to a maximum of about 4000 psi. There are also advantages in using some form of electrical control, such as low-power input signals, small size, and ease of adjusting the performance of the system. In coupling the electrical control and the hydraulic motor, the chief gap to be closed is that between the maximum power of the electrical signal (of the order of 0·001 hp) and the minimum hydraulic power which can be controlled for the usual valve clearances (about 0·1 hp). This means a rather high amplification (approximately 100), and the difficulties encountered in this connection have led the Gloster Aircraft Company (Technical Developments Division) to develop the " mark-space " generator and hydraulic control system. [1]

Some of the electrical power units used are :—

(1) Induction motors, usually with a two-phase winding, one phase being fed from an ordinary a.c. supply and the other by the control signal via an amplifier. The motors are high-speed and hence must be geared down to increase the rather low torque, since the size of such motors is limited by the economics of producing power electronically.

(2) D.C. motors, the smaller sizes of which use field control, and the larger sizes armature control, often by means of thyratrons.

(3) Stepping motors, which rotate in discrete steps, the required table movement corresponding to a definite number of steps, which can be counted electronically.

(4) Electric motors with clutch couplings. If the clutch operates on eddy-current or hydraulic principles, the " amount " of coupling may be made proportional to the magnitude of the control signal.

(4) Measuring Devices or Transducers

As has already been pointed out, it is necessary to know the position of the table at all times, and hence measuring or position-identifying devices are required to convert mechanical displacements into electrical signals, usually voltages. These devices are frequently referred to as transducers.

An immediate classification may be made according to whether the table position is sensed directly, or via the power leadscrew, or via an additional precision leadscrew. The most commonly used devices for sensing table position directly are :—

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[1] M. C. Bennett and F. Henderson : " A Versatile Electro-hydraulic Servo-Control System " ; *British Communications and Electronics*, May 1958, page 394.

(1) Measuring bars and pick-ups (electromagnetic).
(2) Multi-pole resolvers (electromagnetic).
(3) Potentiometers (electrical).
(4) Diffraction gratings (optical).
(5) Interrupted beams of light (optical).
(6) Magnetron beam switching tubes and lobed discs (electronic).
(7) Differential transformers (electromagnetic).

For indirect measurement via a leadscrew, devices include :—

(A) Digitizing discs (electrical).
(B) Magnetron beam switching tubes and lobed discs (electronic).
(C) Potentiometers (electrical).
(D) Synchros (electromagnetic).
(E) Multi-pole resolvers (electromagnetic).

An alternative classification would be into those producing an analogue signal (items 1, 2, 3, 7, C, D, E) and those producing a digital signal (items 4, 5, 6, A, B). This latter classification is of some importance since, if the position-identifying device does not accord with the nature of the system, then a digital-to-analogue or analogue-to-digital converter must be introduced between the measuring unit and the rest of the system.

The chief characteristics of importance in transducers are as follows :—

(1) *Resolution*, i.e., the smallest change in length (or angle) which can be detected by the transducers. The desired position is always an integral multiple of resolution.

(2) *Adherence to function.* Any analogue type of transducer produces an analogue (almost invariably a voltage) which is some function of the mechanical displacement. It is obviously important that this functional relationship be adhered to over the working range of movement as closely as possible. Errors in adherence to function may evidently arise from the inevitable small errors in manufacture, but it has also been pointed out [2] that the loading of the electrical circuit may cause a lack of adherence to the true function.

(3) *Accuracy*, which is somewhat associated with adherence to function, but is really a quantitative expression of the admission that no transducer is perfect, insofar as a point defines where the moving member should come to rest, and a small zone defines the range in which it will come to rest. This zone is the concept which is usually accepted as the accuracy (Fig. 6).

(4) *Repeatability*, which is the accuracy with which the system can repeatedly position the moving member (Fig. 6).

(5) *Response of the transducer to noise.* In electronic circuits, spurious voltage signals are always present and are known as noise. The degree to which the transducer responds to such signals is of importance ; furthermore, some transducers lend themselves to improvement in this respect. For instance, a 10:1 improvement can be effected for a synchro by filtering, i.e., by passing to the synchro only those signals which fall within a certain range of frequencies, while no comparable improvement can be effected for a potentiometer [3].

(6) "*Language*" *of the device.* It has already been pointed out that a transducer feeding an analogue signal to a digital system complicates the circuitry by requiring an analogue-to-digital converter. There are wider implications of this "language" problem, e.g., a transducer which produces a binary-coded signal can be compared with a binary-coded tape with far less circuitry than a transducer producing a decimal-coded signal.

(7) *Mechanical friction*, the most serious aspect of which is wear and consequent loss of accuracy.

(8) *Cost*, which should be taken in conjunction with the cost of the auxiliary equipment mentioned in (6) above.

(9) *Ability to discern change of position.* This is sometimes called (perhaps misleadingly) sensitivity and refers to the largest change in position which can occur before the feedback loop functions completely, though it is not due solely to the measuring element.

It is thus apparent that a good deal of thought must be given to the selection of a transducer and its integration into the control system. To the user of machine tools, this means that, in deciding the merits of a particular system, attention should be paid to the transducer in relation to the rest of the system. Very much bound up with this requirement is the question of whether the system should be absolute or incremental, i.e., whether all positions should be related to some datum (probably arbitrarily chosen) or merely related to the previous position. This point has been given great prominence, particularly in sales literature, but any advantages claimed have nearly always been applied to circumstances which can scarcely be regarded as normal. The most serious aspect of an incremental system (its inability to correct any defection in "counting" from one position to the next) has hardly been mentioned. Fortunately, most incremental systems are designed either to prevent any defections or to make the results of any possible defection so small as to be negligible. An essential feature of such a system is that, if a serious defection occurs, it will close down automatically.

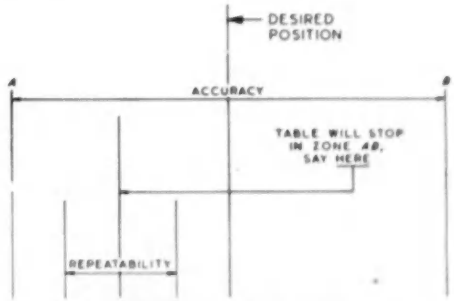

Fig. 6. **Diagrammatic representation of accuracy and repeatability in positioning a moving member.**

The general requirements of a transducer for machine-tool control are much higher than for most applications ; thus, for example, a table which has a travel of 100 in. and has to be positioned to 0·0005 in. requires a resolving power of 1 in 200,000. Few control systems attempt to do this subdivision in one step and, indeed, transducers working from the leadscrew effectively subdivide a length equal to only one pitch of the leadscrew. Under these conditions, ambiguity arises, i.e., the signal from the transducer does not indicate the table position uniquely

[2] K. J. Willis : "The Design of Precision Wire-Wound Potentiometers" ; *Platinum Metals Review*, Vol. 2, No. 3, page 74.

[3] H. A. Dinter, Jr. : "Important Factors Influencing the Choice between a Synchro and a Potentiometer as an Angular Position Pick-off" ; *Trans. AIEE*, Vol. 75, Part II, page 198.

For example, if the signal from the leadscrew transducer indicates zero angle at some instant, it will repeat this zero signal every time the table has moved an integral number of pitches of the leadscrew. Ambiguity is overcome by incorporating some coarse form of positional control ; in the above example, the coarse positional control would have to bring the table to within one pitch of its final position before the signal from the transducer had any real meaning. The addition of such a coarse positioning system obviously means a greater complexity of the general control system but is an easy way of reducing the demands of subdivision, so that, in the numerical case quoted above, the resolving power need be only 1 in 200 with a 10-tpi leadscrew, instead of 1 in 200,000.

So far, no mention has been made of the question of discriminating between the two directions of movement. Some transducers have the ability to discriminate direction, while others have no inherent means of doing so. In the latter case, a solution very frequently employed is to put a second winding on the transducer or to employ two separate transducers in such a way that two signals are obtained, each 90 deg. out of phase with the other. Thus, for one direction the sine signal follows the cosine signal, and for the other direction the cosine signal follows the sine signal.

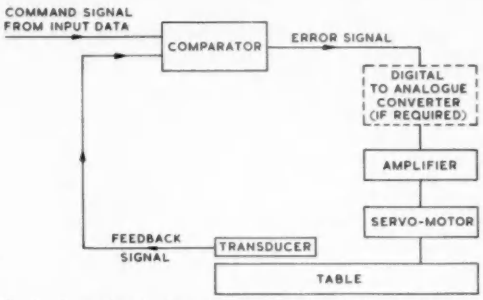

Fig. 7. **Generalized feedback loop for a machine-tool control system.**

(5) The Feedback Loop

In any numerical control system there are two sets of signals, as already discussed, these being the command signals (representing the desired position of the moving

TABLE IV : SUMMARY OF POSITIONAL CONTROL SYSTEMS.

Company	Class of Accuracy	Positional Speed	Storage Medium		Storage Code	Measuring System	
			Temporary	Permanent		Language*	Type
Hillyer	3	15 holes/min	S	14-ch PT	dec	dec	DIGITIZING DISC
Arter	3	9–13 sec	—	5-ch PT	dec	dec	
Kearfott	3	25 ipm	—	PC	bin	Gray	
Laboratory for Electronics	4	1 sec	—	8-ch PT	bin	Gray	
Electrosystems	3	100 ipm	—	8-ch PT	bin-dec	dec	
Norden-Ketay	3	200 ipm	S	8-ch PT	bin-dec	bin-dec	
Barnes Engineering	2	50 ipm	—	32-ch PT	bin	bin	
Airmec	2	90 ipm	S	12-ch PT	dec	dec	
Fuji Communication Apparatus	3	120 ipm	—	6-ch PT	bin-dec	—	
Hilger & Watts	2 or 3	†	S	—	—	bin	
Mullard	3	60 ipm	S	—	—	dec	
National Automatic Tool	3	215 ipm	—	8-ch PT	dec	dec	
General Electric (U.S.A.)	2	60 ipm	S or TD	8-ch PT	bin-dec	—	SYNCHRO
General Electric (U.S.A.)	2	60 ipm	S or TD	PC	dec	—	
Westinghouse Electric	3	†	S	8-ch PT	bin-dec	—	
Westinghouse Electric	3	†	S	PC	dec	—	
Advance Industries	3	150 ipm	—	32-ch PT	bin-dec	—	
Electronic Control System	1	2 sec	—	8-ch PT	bin-dec	—	
Farrand Controls	1	100 ipm	S	8-ch PT	bin-dec	—	MULTI-POLE RESOLVER
Farrand Controls	1	100 ipm	S	PC	dec	—	
E.M.I. Electronics	1 or 2	†	S	5-ch PT	bin-dec	—	
Canadian Westinghouse	1	†	S	—	—	—	DIFFERENTIAL TRANSFORMER
Cleveland Instrument	1	10 sec	—	8-ch PT	bin-dec	—	
Cleveland Instrument	1	10 sec	—	PC	dec	—	
Topp Industries	1	50 ipm	—	MT	—	—	
Fosdick Machine Tool	1	15–20 sec	—	8-ch PT	bin-dec	—	MEASURING BAR
Fosdick Machine Tool	1	15–20 sec	—	PC	dec	—	
Schwartzkopff	1	32 sec	—	PC	dec	—	
Pratt & Whitney	1	†	S	12-ch PT	dec	—	
B.T.H.	1	8 sec	S	PC	dec	—	
Ferranti	1	2 sec	—	5-ch PT	bin-dec	—	DIFFRACTION GRATING
Ericsson Telephones	2 or 3	†	—	5-ch PT	bin	—	
Brush Electrical	3	†	S	—	—	—	
Mullard-Coventry Gauge & Tool	1	4–10 sec	S	—	—	—	
Japanese Government Mechanical Laboratory	1	80 ipm	—	6-ch PT	mod. bin	—	
Wang Laboratories	2	†	—	8-ch PT	bin-dec	—	POTENTIOMETER
Reeves Instrument	1	1–5 sec	—	6-ch PT	bin-dec	—	
Ekco Electronics	2	24 ipm	S	PC	dec	—	
Warner & Swasey	1 to 2	100 ipm	—	8-ch PT	bin-dec	—	MISCELLANEOUS
Modern Engineering Service	1	36 sec/rev	—	8-ch PT	bin-dec	—	
Teller	1 to 2	80 ipm	TD	8-ch PT	dec	—	

* Where the transducer output is a digital signal in a particular counting system.
† Positional speed depends on the machine to be controlled.
S = decade switches. TD = telephone dial. ch = channel.
PT = punched tape. PC = punched cards. MT = magnetic tape.
bin = binary. dec = decimal. mod. bin = modified binary.

member) and the transducer signals (representing the actual position of the moving member), which are frequently referred to as the feedback signals.

These two signals should be the same at all times ; however, in any system (positional or continuous) the command signals change in finite steps, no matter how small, and the table cannot assume its required position instantaneously. Consequently, on comparing the two signals, there will be, in general, a difference, called the error signal, which is used to actuate the servo-motor driving the table. The servo-motor will cease to drive the table when the error signal disappears, i.e., when command and feedback signals are the same. In a positional-control system this will occur when a required setting of the table has been reached, whereas in a continuous contour control system this situation will be achieved only at the end of the machining operation.

Fig. 7 shows a generalized feedback system for a machine tool. It has been mentioned previously that this is an error-actuated system, and consequently corrective action is always a little behind the error (in time). This delay and the stability of the system are two of the chief topics discussed in any text on control engineering ; certainly, within the scope of this survey, scant justice can be done to the subject, but the idea of the closed feedback loop is the heart of the problem, as it enables the system to " think ", to a limited extent, and so distinguishes it from the most advanced form of mechanization, where all thinking must be done in advance by the designer.

POSITIONAL CONTROL SYSTEMS

A positional control system is used for controlling the final position of a moving member and exercises no specific control over the intermediate path taken, so that certain requirements are less stringent than they are for continuous contour control. The first (and probably most obvious) relaxation in demands on the control system is that, since the path of movement is immaterial, questions of approximating to it do not arise, and a considerable part of the equipment required for continuous contour control is not required, including the computer.

Again, in controlling more than one axis, no synchronization of control signals is required ; indeed, the movements parallel to the different axes could be made consecutively (as distinct from simultaneously), although this would obviously increase the positioning time. Furthermore, the time element is not critical, and the performance of the whole feedback loop, as regards phase delay, is less severe.

In the consideration of positional control systems, the main subdivision has been according to the type of transducer used. Brouwer [4], in his discussion of measuring devices, has given two classes of transducers, i.e., coarse and fine. The ultimate accuracy of positioning, however, depends on many other factors and, as statements of accuracy are rarely guaranteed, it has been deemed advisable to classify degrees of accuracy more generally, as indicated in Table III.

TABLE III: CLASSIFICATION USED FOR ACCURACY OF POSITIONAL CONTROL SYSTEMS.

Class	Order of Accuracy
1	< 0·0005 in.
2	0·0005 to 0·001 in.
3	0·001 to 0·003 in.
4	> 0·003 in.

It should be appreciated that positional control systems can effect improvements only in the time of positioning and the reduction of operator fatigue. The machining time is still the same and, as a general rule, positional control is more effective in cases where a large number of holes must be drilled with medium positioning accuracy.

[4] F. BROUWER : " A Critical Evaluation of High-Precision Electromechanical Linear Measuring Systems " ; *Electrical Manufacturing*, August 1957.

These systems, the details of which are summarized opposite in Table IV, will now be considered separately, according to their transducers.

Systems using Digitizing Discs

Since the common feature in systems of this type is the use of a rotating disc to produce a digital signal, it will be apparent that most of the systems will be entirely digital and that the remainder will have an analogue-to-digital conversion in the system. These systems have either Class 2 or Class 3 accuracy (Table III) and might be more broadly described as of medium accuracy.

Many of the systems make great use of electrical relays, which are, of course, a standard item of telecommunications equipment. A typical relay system is that of the Hillyer Corporation ; this system is entirely digital and decimal, the input being 14-channel punched tape. The measuring element is a series of five counter discs using printed-circuit contacts ; brushes, driven by the leadscrew, through appropriate gearing, move over the surfaces of these discs and, through the constant make-and-break of the contacts, give a digital signal which is proportional to the position of the moving member. Obviously, the brushes for the 0·01- and 0·001-in. discs would rotate at a very high speed at normal table velocities, and hence solenoids are provided for lifting these brushes until the positional error is small, at which point the table velocity is low. The table position, as indicated by the digital signal from the discs, is compared with the command information from the punched tape, and the difference, i.e., error signal, causes the servo-motor to drive the table so as to make this error zero. Fig. 8 shows a Hillyer drilling machine equipped with this control system.

A similar system, also completely digital, is that used by the Arter Grinding Machine Company for their Arter " Jigmatic " Model 250. Here again, the brushes for the two least significant digits are lifted during the main positioning but, in this system, clutches are used, and there is a synchronizing commutator for bringing the fourth and fifth stages in at the correct point with reference to the first three stages, as shown in Fig. 9, which illustrates the printed-circuit board and also

Fig. 8. **Drilling machine equipped with a Hillyer numerical-control system using digitizing discs.**
(*Courtesy of Hillyer Corporation*)

includes the digital commutators. This system minimizes backlash errors by positioning from the same direction always, and the table is held, during the operations, by means of a magnetic clamp.

The Kearfott Company and the Laboratory for Electronics Inc. both use similar measuring systems to those just described, but, instead of employing the decimal system, the Gray or cyclic binary system (Fig. 4) is used. The numerical advantages of this code have already been discussed, but additional advantages are simplicity in the subtractor circuit and the fact that high-precision components are unnecessary ; furthermore, it enables the system to be quick in positioning (the system of the Laboratory for Electronics, in particular, positions in an average time of 1 sec) but, since the comparison is effected digit by digit in the binary code, any given number requires more digits than in the decimal code and hence a more elaborate network of relays or switches. It may be felt, however, that this is a comparatively small penalty to pay for a system which is virtually devoid of any electronic equipment.

The Kearfott Company markets individual components to those wishing to manufacture control systems and does not produce a complete system of its own. The block diagram in Fig. 10 shows the details of single-axis control of the Laboratory for Electronics system ; the Kearfott system is similar, except that it has no buffer storage, since all the tape information is read simultaneously. It will be seen that, after the command and table-position signals have been compared, the error signal is converted to a voltage analogue which, after amplification, controls the table-positioning servo-motor.

One rather interesting feature of the Laboratory for Electronics system is that it uses conventional engineering vulgar fractions and not decimal fractions, apparently because this system is applied specifically to drilling, where the pitch of holes is still often given in vulgar fractions. It should, however, be pointed out that, in the binary system, these are ordinary, as well as vulgar, fractions, inasmuch as $\frac{1}{2} = 2^{-1}$, $\frac{1}{4} = 2^{-2}$, $\frac{1}{8} = 2^{-3}$, etc., and all conventional engineering fractions can be expressed in terms of these units ; thus, for instance, $\frac{3}{8} = \frac{1}{4} + \frac{1}{8}$, so that $4\frac{3}{8}$ in the binary system becomes

$$2^2 + (0 \times 2^1) + (0 \times 2^0) + (0 \times 2^{-1}) + 2^{-2} + 2^{-3} = 100{\cdot}011.$$

Fig. 11 shows the Laboratory for Electronics composite unit for numerical control of drilling operations. The tape-reader can be seen behind the glass panel at the right of the machine.

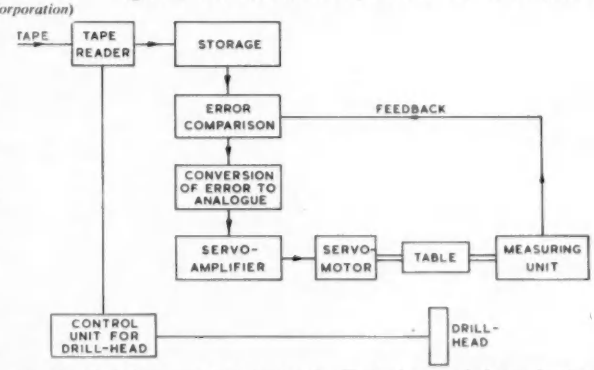

Fig. 10. **Block diagram of the Laboratory for Electronics numerical-control system.**

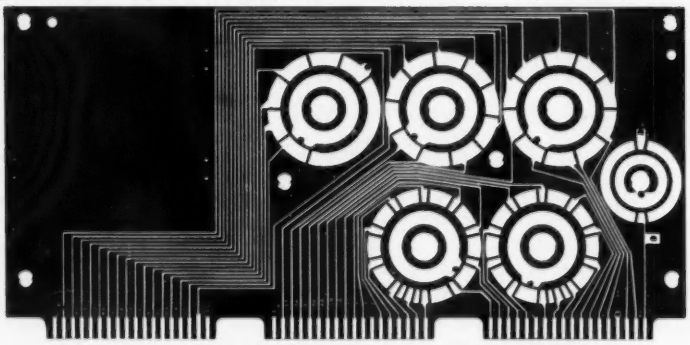

Fig. 9. **Printed-circuit digitizing discs of the Arter numerical-control system.**
(*Courtesy of Arter Grinding Machine Co. Inc.*)

The systems produced by Electrosystems Inc. and by the Norden-Ketay Corporation are generally similar to the two previous systems, but the rotating discs employ the decimal, as distinct from the binary, system.

The " Binotrol " system of the Barnes Engineering Company is one of the few which utilizes the conventional binary scale throughout its operation, but its chief point of interest is its relay network, which compares input and feedback information without analogue conversion. For each digit, there is a pair of relays, one

Fig. 11. Drilling machine fitted with the Laboratory for Electronics numerical-control system.
(Courtesy of Laboratory for Electronics Inc.)

operated from the tape-reader and the other from the digitizer. When correspondence between command and feedback is achieved, the table-drive is stopped. The system uses 32-channel tape and accommodates two 15-digit binary numbers, giving, for the sum of the terms of a geometrical progression, $2^{15} - 1 = 32{,}767$ units of 0·001 in. each, i.e., a range up to 32·767 in.

A British company which has recently entered the numerical-control field is Airmec Ltd., which is probably more widely known for its telecommunication equipment. The required table position may be set up manually by means of decade switches, or automatically, using 12-channel paper tape coded decimally, according to the scheme in Fig. 12, which shows the coding for one axis. Thus ten channels are needed to code the numerical data

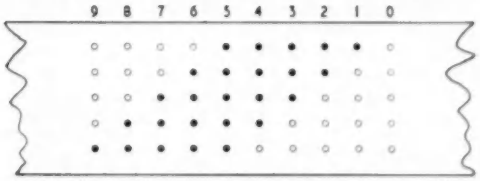

Fig. 12. Numerical coding system for the control tape used in the Airmec system.

for the X and Y axes, and the two remaining channels are used for tool selection, tape rewind, and other special functional commands.

The information is read in the tape-reader by spring-loaded feeler pins, and the movement of the tape is controlled by a photo-transistor receiving light through holes in the tape which are smaller than the digit holes. The information is stored in a relay buffer stage until the positioner unit is ready to receive it. The position unit contains a series of rotating discs which act as decimal commutator switches, the first of which is driven directly from the leadscrew. There is a 10:1 gear ratio between the successive disc shafts. Each disc has a number of sections which may be connected together to provide what is basically a two-segment commutator, each segment of which is maintained at such a potential as to provide either a forward or reverse movement of the motor driving the leadscrew. The angular setting of these two segments is controlled by the relay system in the buffer storage. When any disc moves to a position where the brush rests in the neutral zone between the two segments, control passes to the next-finest disc.

At any of the points where control is transferred, a magnetic clutch can be operated to reduce leadscrew speed, so as to obtain a slow " run-in ". When the last disc has reached its correct position, the magnetic clutch is released, thereby disconnecting the motor from the leadscrew, and a signal is provided for operating the table clamp. In one direction of travel, the settings of the segments are deliberately advanced so as to ensure that final positioning always takes place from the same direction, minimizing the effects of backlash. A correction cam is provided to compensate for cumulative errors in the leadscrew, and the cam is cut from the measured errors of the leadscrew. Fig. 13 shows Airmec control equipment applied to a small machine which may be used for co-ordinate drilling.

A Japanese system, produced by the Fuji Communication Apparatus Manufacturing Company, employs an

Fig. 13. The Airmec two-dimensional positioning system applied to a machine-tool table.
(Courtesy of Airmec Ltd.)

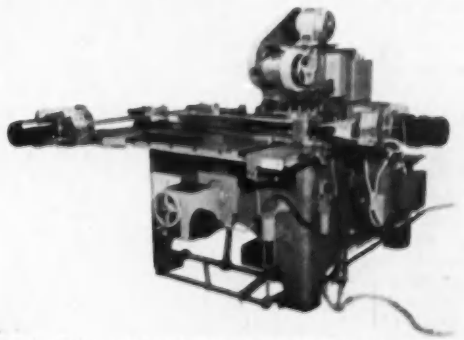

Fig. 14. Application of the Fuji system for the two-dimensional control of a Wiedemann press.
(Courtesy of Fuji Communication Apparatus Mfg. Co.)

aluminium disc with twelve equally spaced holes on an inner radius for generating pulses and twelve armatures on an outer radius for electromagnetic braking. The table position is sensed by counting the pulses generated by this disc with the aid of a parametron, which was developed at Tokyo University and is a high-frequency electromagnetic device with flip-flop characteristics, thus rendering it suitable for pulse counting. This system is comparatively cheap, although a direct price comparison with British and American systems is not easy. Fig. 14 shows a Wiedemann press fitted with the Fuji system for two-dimensional control.

The British firm of precision-instrument manufacturers, Hilger & Watts, has taken a particular interest in the development of digitizers of many kinds and has employed them in systems of positional control. Fig. 15 shows one such digitizer unit mounted on a boring machine and sensing the table position through a precision rack-and-pinion drive. The unit actually contains two digitizers, one giving a reading up to 9·999 in., and the pair, in combination, covering the remainder of the range up to 249·999 in. in 0·001-in. steps. The two digitizers are geared together in such a way as virtually to eliminate backlash.

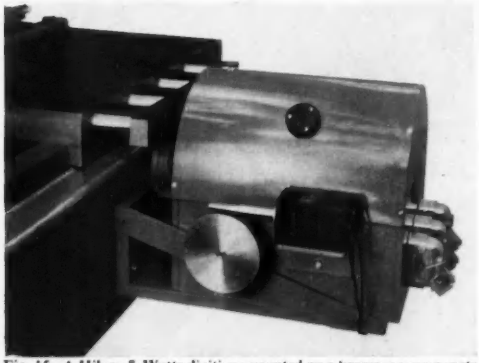

Fig. 15. A Hilger & Watts digitizer mounted on a boring-machine table. *(Courtesy of Hilger & Watts Ltd.)*

For this system, optical digitizers are used, these being the optical analogues of the mechanical digitizers discussed previously, with the alternate conducting-insulating nature of the electrical contacts replaced by a pattern of transparent-opaque marks. During rotation of the disc, the opaque marks interrupt a stationary beam of light which is focused on a photocell detector, and thus short electrical pulses are produced. The resolution with a 2¼-in. diameter disc is of the order of 1 in 1000. The advantages of an optical digitizer, as compared with a mechanical digitizer, are (1) a much lower resisting torque and a longer life, owing to the absence of actual contact, and (2) a smaller size for the same resolution.

In the Hilger & Watts system a continuous display of the table position is provided on a panel. This may be either a single-row display or the type shown in Fig. 16, employing columns of numbers, each of which may be illuminated by a small lamp controlled by the relays of the decoding system. Table movement may be either manual or power-driven ; in the latter case, automatic switching is employed in the final positioning of the table. Various applications of the range of Hilger & Watts digitizers have been discussed by Evans [5].

[5] D. S. Evans : "The Digitiser—a High-Accuracy Scale for Automatic Data Processing" ; *British Communications and Electronics*, June 1957, page 334.

Fig. 16. The Hilger & Watts multi-column display unit for indicating table position. *(Courtesy of Hilger & Watts Ltd.)*

In concluding this brief survey of the several systems using digitizing discs, the Mullard "Autoplot" system should be mentioned. This British system is modest in price and is of relatively low accuracy, as it is intended mainly for marking out sheet-metal parts and for drilling chassis and templates. The digitizing disc in this case is a toothed scanning disc geared to the leadscrew. Each pulse corresponds to a work-head movement of 0·001 in., the work-head moving (rather than the table), in order to minimize backlash errors.

The X and Y co-ordinates of the required position are fed into the system by dials, although punched cards can be used. The measured information passes to a counter having five dekatron tubes, and the work-head continues to move until the number of pulses registered on the dekatron tubes is equal to that set on the input dials.

Systems using Synchros (or Resolvers)

A synchro is an electromagnetic device for converting an angle to an analogue voltage or vice versa. It consists of a polyphase stator winding and a single rotor winding. The stator winding may be three-phase or two-phase, and, although synchros, as a whole, are often referred to as resolvers, it might be preferable to restrict the term "resolver" to the two-phase synchro, bearing in mind that the term "multi-pole resolver" refers to a two-phase resolver.

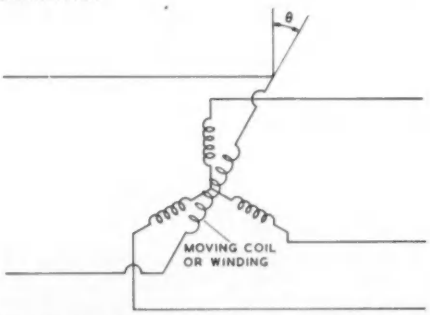

Fig. 17. Diagrammatic representation of a synchro with a three-phase stator winding.

When the stator is excited by a three-phase voltage, the voltage induced in the rotor winding is proportional to the sine of its angle of rotation θ (Fig. 17), thus providing the analogue for the angular position. Synchros

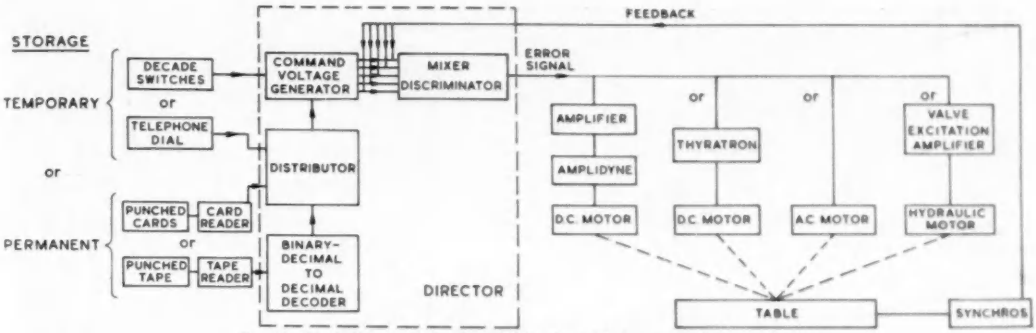

Fig. 18. **Block diagram of the General Electric positioning system for one axis.**

have a general accuracy of the order of 20 minutes of arc, but special synchros are available which will measure to 1 minute. It should be borne in mind that a 20-minute synchro will give about 0·0001 in. accuracy with a lead-screw having a pitch of 0·1 in. In this connection, systems using synchros fall roughly into Classes 2 or 3 in Table III as regards accuracy.

The General Electric Company (U.S.A.) has a Specialty Control Department which has developed an absolute system based on synchros as the measuring element. This company has been active in the machine-tool control field since 1947, first with playback systems and later with numerical control. In 1954 the company fitted its positional control system to a Wiedemann punch press, and it is believed to be one of the earliest, if not the earliest, application of positional control. The storage medium can be either 8-channel punched tape or standard Remington-Rand or IBM (International Business Machines Corporation) punched cards, though manually set dials may also be used to feed in the information. Alternative methods of table control are also possible and can be effected by a d.c. motor with either amplidyne or thyratron control, an a.c. motor, or an electro-hydraulic motor, as shown in Fig. 18, which is a block diagram of the General Electric system for one axis. For multi-axis control, the servo-motor and parts of the director are repeated for each additional axis. The director is the section of the control contained within the broken line in Fig. 18 and its functions are (1) to convert the input information (in digital form) into command information (in voltage analogue form), and (2) to discriminate the difference between these command voltages and those fed back by the synchros, and hence to generate an error voltage.

To convert input information into command information, command-voltage transformers are used, these having a single primary winding and a centre-tapped secondary winding which is further tapped so as to divide the output voltage decimally on each side of the centre tap (Fig. 19). These tappings are led to decade stepping switches which are ganged to a third switch, controlled (as regards position) by the information from the card-reader ; for example, if the number to be set is 18·735, the information from the card-reader for the " units " figure is 8, and the stepping switch will rotate until it reaches position 8. At this point, the voltage tapped from the secondary of the transformer will be eight-tenths of the voltage corresponding to a full rotation of the " units " synchro. In addition to this function, the stepping switches also act as a buffer storage. The command voltages for all four synchros are derived in a similar manner. It will be noted that there are only four synchros, but five digits must be controlled. Actually, three of the synchros correspond to tens, units, and tenths

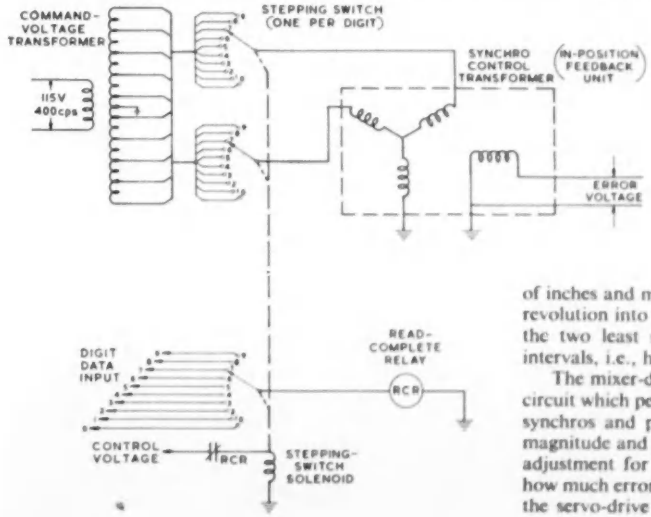

Fig. 19. **Method used in the General Electric system for making the digital-to-analogue conversion.**

of inches and move in 36-deg. increments, i.e., divide the revolution into ten parts, whilst the fourth synchro is for the two least significant digits and moves in 3·6-deg. intervals, i.e., hundredths of a revolution.

The mixer-discriminator in Fig. 18 provides a mixing circuit which performs the switch-over from coarse to fine synchros and produces a signal indicating the error in magnitude and position. The system is provided with an adjustment for setting the dead zone, i.e., for deciding how much error signal is to be tolerated before energizing the servo-drive which positions the table.

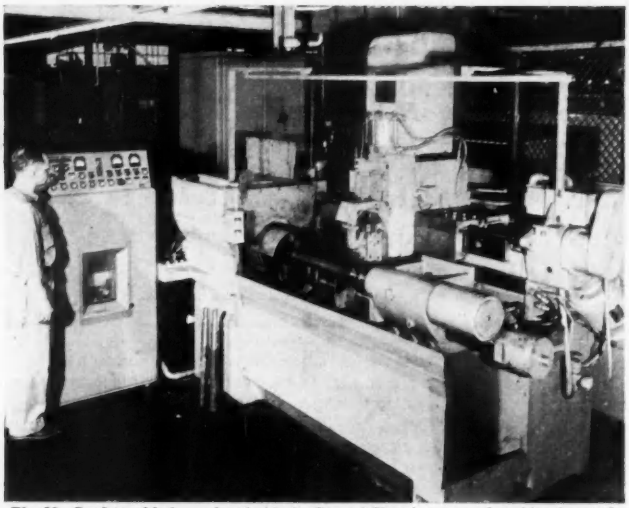

Fig. 20. Sundstrand lathe equipped with the General Electric system of positional control. *(Courtesy of General Electric Co. (U.S.A.))*

Fig. 20 shows a Sundstrand lathe equipped with the General Electric system of numerical control. This lathe is used for turning stepped shafts and is particularly suitable for very small batch work, in which production-rate increases of over 75% have been achieved. The average increase for all jobs is about 50%.

The Westinghouse Company (U.S.A.) offers two control systems. One of these is a relatively accurate system in which coarse positioning is achieved by synchros, and fine positioning by a differential transformer, so that it is, in effect, the Canadian Westinghouse system described in a later section of this survey. The other system does not have fine positioning and is thus a coarser system, but, even so, any loss in accuracy is most pronounced only when longer table movements have to be controlled.

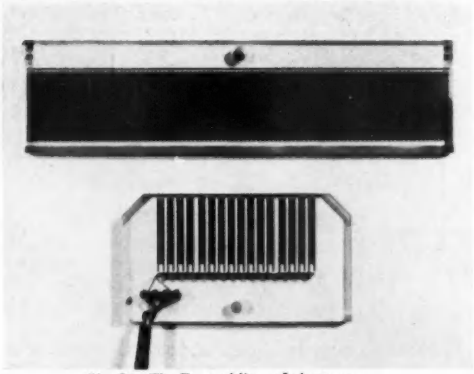

Fig. 21. The Farrand linear Inductosyn. *(Courtesy of E.M.I. Electronics Ltd.)*

Advance Industries Inc. have a system which has been adopted by the Jones and Lamson Machine Company for integration with drill heads, of which the Cincinnati-Bickford is a typical example. The storage medium is 4-in., 32-channel Mylar tape. As with the General Electric system, there is a conversion of the binary information (read from the tape) into decimal form, followed by stepping switches and tapped transformers used to generate the voltages for the synchros.

In passing the control successively from the coarsest to the finest synchro, an overlapping technique is used to ensure that one synchro is not cut out before the next is switched in. For each synchro, this is achieved by deriving a bias voltage from an additional tapped transformer and applying this voltage to the rotor winding of the synchro ; in this way, although the true voltage in the rotor winding may be zero, there is still an additional voltage which delays the cutting out of that particular synchro.

The table drive is by a hydraulic servo, i.e., a piston (integral with the table) moving in a cylinder containing oil under high pressure, the piston position being monitored by a rotary differential valve driven from a leadscrew. Obviously, this leadscrew does not have to transmit power, thereby minimizing errors due to wear, backlash, and elastic deflection.

The system developed by Electronic Control Systems Inc. for continuous contour control is described fully in a later section of this survey. It should, however, be noted that it can also be used for positional control, in which case a computer is not required.

Systems using Multi-Pole Resolvers

The operation of a Multi-pole resolver is fundamentally the same as that of a two-pole resolver, which has one rotor winding and two stator windings at 90 deg. to one another. If the rotor is excited by a constant voltage, the voltages induced in the two stator windings will vary as the sine and cosine of the angular displacement, thus defining the angular setting of the resolver. The system may be worked in reverse, i.e., synchronized sine and cosine voltages may be applied to the stator windings and the rotor rotated until the voltage induced in it is zero. This position, again, is a unique function of the sine and cosine voltages.

The multi-pole resolver is a development of the Farrand Optical Company Inc. and has led to the formation of a subsidiary company, Farrand Controls Inc., which has developed a system of positional control using the multi-pole resolver or " Inductosyn ". Apart from the advantage of multi-polar operation, the Inductosyn has the additional virtue that it can be made in either linear or rotary form ; the linear type is especially useful for systems working in rectangular co-ordinates.

The first element of the linear Inductosyn (Fig. 21) is a glass scale, about 10 in. long, with a single hairpin winding of metallic conducting material printed on it. The second element, known as the slider and shorter in length than the scale, has two printed metallic windings spaced at 90 electrical degrees or 0·025 in. Hence, two complete double-turn windings, or four poles, correspond to 0·1 in. on the slider.

The scale, or a number of scales end to end, is mounted on the fixed member, whilst the moving member carries one slider. The distance separating the scale and slider is about 0·010 in. and is not critical. In the Farrand system, the slide is moved in the following way :—

Sine and cosine voltages, which are the analogues of the dimensional information, are fed to the slider windings.

In general, the moving member will be in such a position as to cause an error voltage to be induced in the scale winding ; this error voltage is used to actuate a servo-drive, and evidently, when the moving member is positioned, the error voltage disappears and the servo-drive ceases. It is clear that, as the voltage passes through zero every 0·05 in., i.e., twice in every four poles, a coarse system must be employed to position to within 0·05 in., and the Inductosyn will then perform the final positioning. The Inductosyn can resolve to 0·36 = 360/1000 electrical degrees, i.e., it can resolve to 0·0001 in.

The co-ordinate information is converted in a Flexowriter into 8-channel punched-paper tape, the numerical information being in binary-decimal code. Fig. 22 gives details of the Farrand system, in which position commands come from decade switches, which may be operated manually or by a tape-reader. The function of the electronic switches is to connect the resolvers to the amplifier-motor circuits in the correct sequence, i.e., coarse (for positioning the tens and units of inches), medium (for positioning 0·1- and 0·01-in. steps), and fine (for 0·001- and 0·0001-in. steps), in that order.

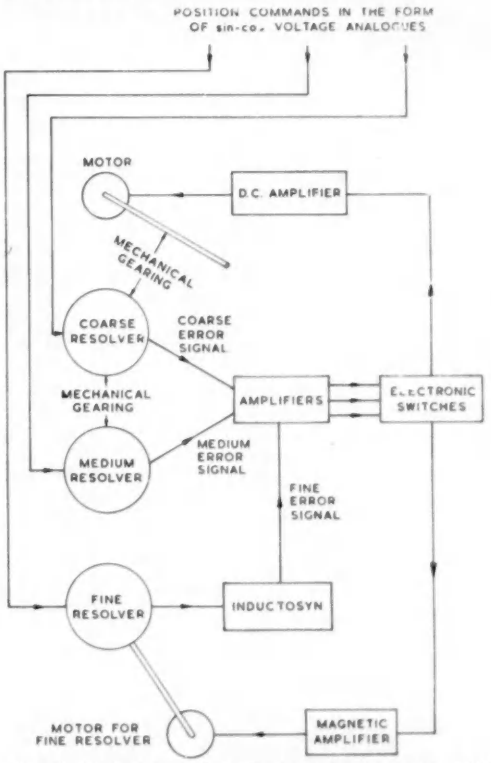

Fig. 22. **Block diagram of the Farrand positioning system, using the Inductosyn as the fine transducer.**

The coarse and medium resolvers are synchros working through gearing from the leadscrew, which is driven by a motor controlled by a d.c. amplifier. The fine resolver, also a synchro, is driven by a motor actuated by a magnetic amplifier.

A British company, E.M.I. Ltd., has been prominent in the field of numerical control and has developed a system of Class 1 accuracy, in which the Inductosyn is the fine transducer. Fig. 23 is a block diagram of this system, in which an array of six decade switches provides a temporary storage medium, permanent storage being provided by 5-channel punched tape. Four of these channels are used for encoding the numerical information in binary-decimal form (Fig. 3c), while, apart from the " stop " signal, the fifth channel is used only in conjunction with the other channels and is reserved for non-numerical commands.

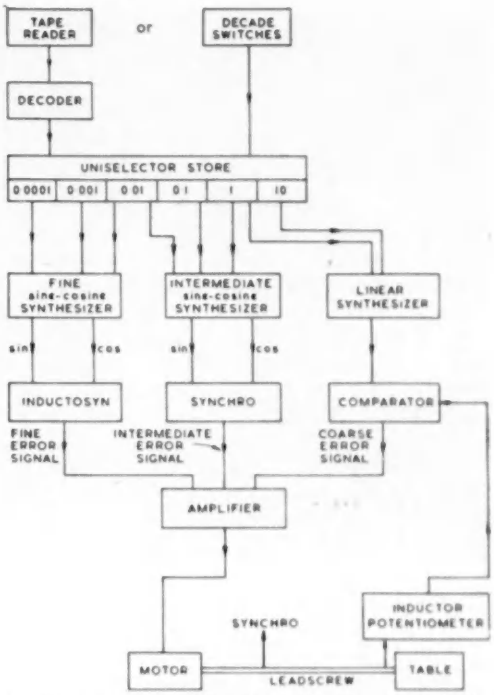

Fig. 23. **Block diagram of the E.M.I. positioning system, using the Inductosyn as the fine transducer.**

The switches feed directly to the uniselector store, but the output from the tape reader passes first through a decoder, which is effectively an electrical means of converting the signals from the reader into a form suited to the uniselector store. This store consists of six banks of uniselector switches similar to those used in automatic telephone exchanges.

The output from the tens and units banks passes to a " linear synthesizer " whose function is to produce a voltage proportional to the commanded coarse displacement, i.e., the tens and units of inches. This voltage is compared with the feedback signal from the coarse transducer, which in this system is an inductor potentiometer (or auto-transformer) driven through gearing from the leadscrew. The voltage resulting from this comparison can be called the coarse error signal.

Returning, for the moment, to the uniselector store, the outputs from the units, tenths, and hundredths banks are fed to a " sine-cosine synthesizer ". This is a complex network of switches and transformers, to the development of which the company has given considerable attention, and its function is to generate a pair of sine and cosine voltages which are the analogue of the units, tenths, and hundredths figures. These voltages are fed to the stator windings of a two-phase synchro whose rotor

Fig. 24. **Portal-type drilling machine fitted with the E.M.I. system of positional control.** *(Courtesy of E.M.I. Electronics Ltd.)*

is coupled via gearing to the leadscrew. In general, the rotor will not be in the zero-voltage position ; indeed, the voltage induced in it will be proportional to the difference between the commanded and actual positions (as regards units, tenths, and hundredths of inches) and can be termed the intermediate error signal.

The outputs from the hundredths, thousandths, and ten-thousandths banks of the uniselector are fed to a second sine-cosine synthesizer, producing a pair of sine-cosine voltages which are the analogue of the three least significant figures. This pair of voltages is fed to the stator windings of an Inductosyn, which senses the table position directly. As with the synchro, there will be a voltage induced in the rotor winding until the commanded position has been reached, and this can be termed the fine error signal.

These three error signals are all fed to a servo-amplifier via electronic switching, arranged so that the initial input to the amplifier is the coarse error signal but, when this has decreased below a certain magnitude, the intermediate error signal becomes the input. Later, when this has decreased in magnitude to some predetermined amount, the fine error signal becomes the input. In this manner, control passes from coarse to fine systems. The output from the amplifier controls the speed of the servo-motor.

It will be seen that the ambiguity of the Inductosyn is resolved by means of the synchro and, in turn, the ambiguity of the synchro by means of the inductor potentiometer. The company also caters for a less refined system using only the linear synthesizer and inductor potentiometer.

Fig. 24 shows a portal-type drilling machine, built by Industrial Technics Ltd., fitted with this system of control, which has a positioning accuracy of the order of 0·0001 in. and a repeatability of a few hundred-thousandths of an inch.

E.M.I. have given careful consideration to the problem of control in cases where the traverse is greater than 100 in. It will be evident that, for a given resolving power, the total travel to be controlled can only be increased ten-fold if the least significant digit is sacrificed, or, to put it another way, only a given number of digits can be controlled, irrespective of the location of the decimal point. If it is desired not to sacrifice this last digit, then the traverse can only be increased by allowing the existing system to repeat every 100 in. This, however, gives rise to two problems :—

(a) The system, as a whole, is ambiguous and cannot distinguish between, say, 53, 153, 253, etc. The theoretical solution to this problem is easy, requiring, as with all ambiguities, a coarser system of control. The practical solution, however, is not effected so easily, but E.M.I. have designed a satisfactory coarse system using microswitches to position to the nearest 50 in., i.e., to within 100 in.

(b) There must be perfect continuity at points where the system passes from 99·999 in. back to zero. Some link is required at these points, and this has been provided by the facility of indefinite repetition of the tens of inches digit, achieved by an ingenious technique involving the switching of a toroidal transformer which performs the voltage division. This technique is known as the " extended analogue range " technique and is featured in the continuous contour control system known in the U.S.A. as the Cincinnati numerical control system and referred to later in this survey as the Cincinnati-E.M.I. system.

Systems using Differential Transformers

Of the three systems to be mentioned in this section, two (Canadian Westinghouse and Cleveland Instrument) use the differential transformer as a precision analogue transducer, whilst the Topp Industries system employs the differential transformer, in conjunction with a low-power stepping motor, as a digital transducer ; all three systems give Class 1 accuracy.

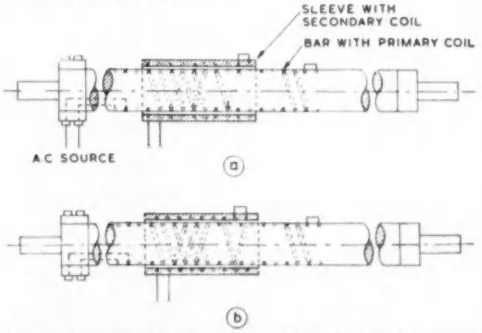

Fig. 25. **The differential transformer used as the transducer in the Canadian Westinghouse positioning system.** *(Courtesy of Canadian Westinghouse Co. Ltd.)*

The Canadian Westinghouse system is handled by a subsidiary, Hamilton Controls Inc., and employs the transducer shown in Fig. 25, and which consists of two electromagnetically coupled elements. The primary

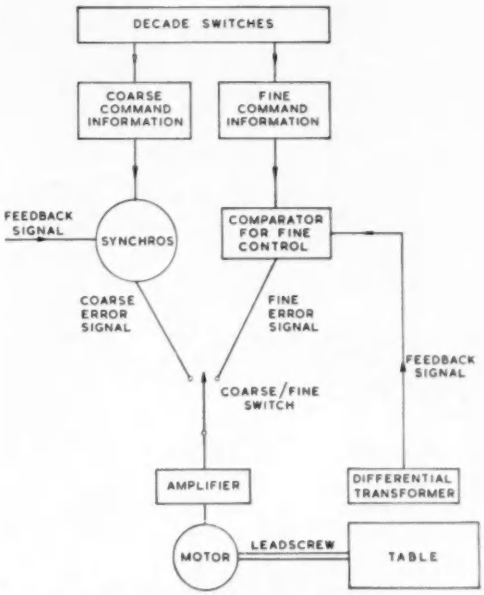

Fig. 26. **Block diagram of the Canadian Westinghouse positioning system.**

winding is located in the surface of a long cylindrical bar, which is either of solid insulating material or is a metallic bar with an insulating sleeve. A two-start square thread is cut in the surface of this bar, and the primary winding consists of a single conductor in each helix, the two conductors being joined at one end and brought to slip-rings at the other. The secondary winding is also a bifilar winding, of the same form and lead as the primary, but shorter in length and wound on the inside of a sleeve, which is a sliding fit over the primary bar.

If an alternating voltage is applied to either winding, a voltage will be induced in the other winding ; this voltage will be a maximum (positive or negative) when the turns of the primary and secondary are aligned, as in Fig. 25a, and will vary in an approximately sinusoidal manner as the sleeve is displaced axially relative to the bar. The voltage will, of course, go through one complete cycle for a relative movement equal to the lead of the windings (usually 0·1 in.), and will be zero for the relative position shown in Fig. 25b.

Thus, as with many transducers for continuous movement, there is a certain ambiguity, and, to position the moving members to within 0·1 in., use must be made of a coarse control system, as mentioned in the Westinghouse system on page 386. At this stage the error signal of the coarse servo is too weak to operate the motor, and control is switched to the fine system, which can now employ the differential transformer as a transducer, without ambiguity.

The system is shown, in block form, in Fig. 26. Assuming for the moment manual setting, the coarse decade switches are used to set up the tens, units, and tenths of inches, and a conventional positional servo-motor brings the moving member within about 0·1 in. of its final position. The three least significant figures are set up on the fine decade switches, which are used to increase the resolution of the differential transformer beyond 0·1 in. It is apparent that, when the inner member of the differential transformer, which carries the primary winding, is rotated through one revolution, the signal generated in the secondary winding will vary in the same way as if the sleeve were moved axially through 0·1 in. The revolution need only be divided into increments of about 0·3 deg. in order to extend the corresponding linear resolution to 0·0001 in. The inner member is carried in precision journal bearings, and a small servo-motor is the controlling unit. Local errors in lead are minimized by using a fairly large number of turns, thus averaging out the error. Eccentricity of the sleeve relative to the bar has no effect on accuracy, and the system can be easily adapted to work from information fed on punched cards or tape.

The differential transformer of the system used by the Cleveland Instrument Company is based on the vernier principle and operates only when approximate positioning has been achieved by means of a conventional bridge-balancing network. Referring to Fig. 27, which applies to the rotary version of the control, the table carries 360 rotary armature slugs at a spacing of exactly one degree, and the machine frame has 15 exciter coils and 15 differential windings at a spacing of 56 minutes. Since the windings are differential, the output voltage from the coils is zero when one of the slugs is exactly in line with an exciter-coil differential winding element. Successive slugs will

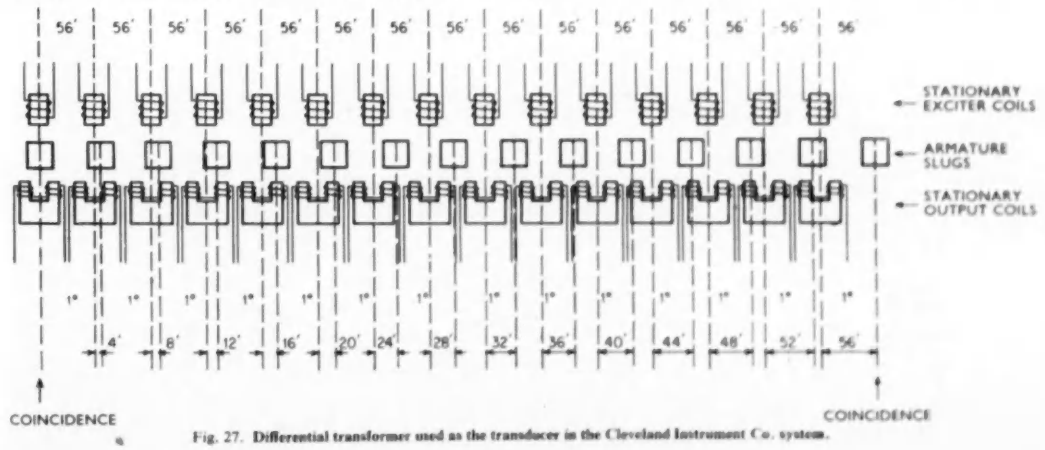

Fig. 27. **Differential transformer used as the transducer in the Cleveland Instrument Co. system.**

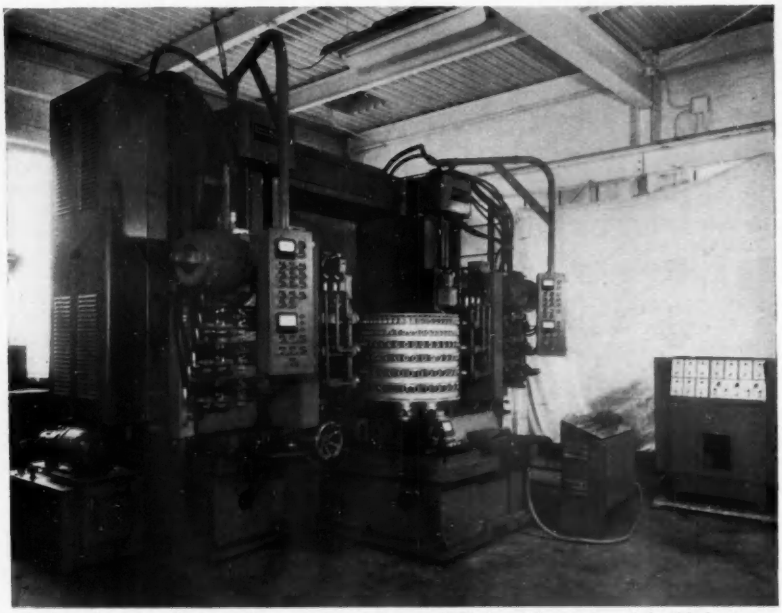

Fig. 28. **Cleveland Instrument Co. system applied to a multi-spindle boring mill.** (*Courtesy of Cleveland Instrument Co. Inc.*)

be increasingly out of line by 4-minute intervals, and thus the system will resolve to 4 minutes by this technique. This resolution is increased 240 times, i.e., to 1 second of arc, not by nulling the differential transformer output but by bringing it to some value dependent on the command information. Since the transformer output is linear over the required range, this is achieved comparatively easily.

The input information is stored on decimally coded Remington-Rand punched cards, or on 8-channel punched tape, using a decimal-binary code, multi-stage decade switches storing this information. The 100-deg., 10-deg., 1-deg., and 10-min. selector switches produce a resistance analogue in one arm of a bridge circuit, the adjacent arm being a 360-deg. potentiometer winding on the rotary table. When these resistances are not equal, there is a voltage across the bridge, and this voltage is the error signal, which actuates the servo-motor (through a d.c. amplifier) and controls coarse positioning.

The system may be supplied for control in rectangular co-ordinates giving a resolution of $\pm$ 0·0001 in. Fig. 28 shows the Cleveland Instrument system applied to a six-spindle boring mill for machining jet-engine casings.

The system developed by Topp Industries uses a stepping motor similar to that employed in the Teller system (see page 399), but it is employed, in this instance, as a measuring instrument and not a power drive. Fig. 29 shows schematically this measuring system, which is digital in operation. Pulses from a magnetic tape (which is the storage medium) are fed alternately to opposite poles of the stepping motor, which moves through 9 deg. for each pulse. Thus, the comparator screw is made to rotate, displacing the steel tuning slug and unbalancing the secondary coils of the differential transformer. The unbalance signal causes the servo-motor to re-centre the slug and, in so doing, to rotate the leadscrew and hence move the table. The amount of table movement is 0·0002 inch per pulse.

The method of tape preparation is rather unusual, in that variable-frequency pulse generators generate pulses which, under human control, move the table as required ;

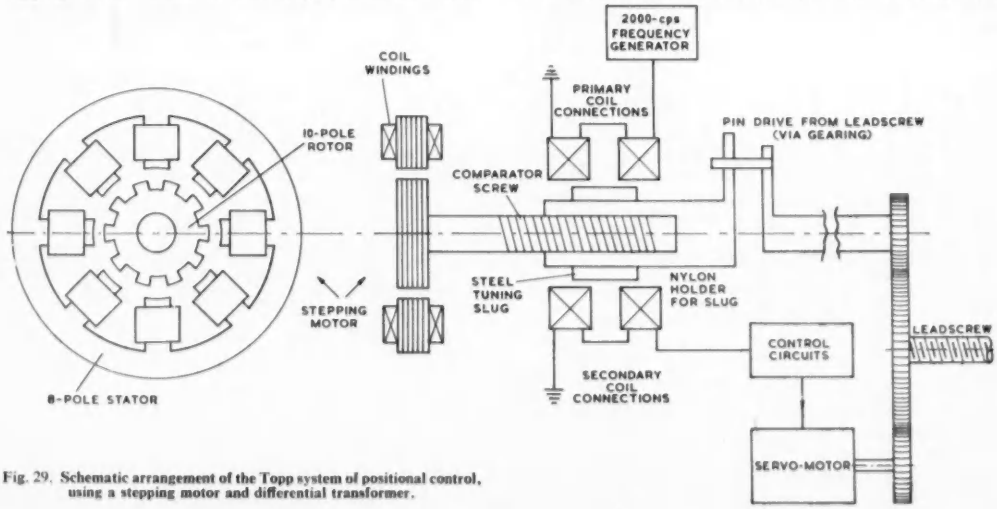

Fig. 29. **Schematic arrangement of the Topp system of positional control, using a stepping motor and differential transformer.**

during this time, the pulses are recorded on magnetic tape, which then acts as the information input for the actual operation cycles.

Systems using Measuring Bars

A system using some form of measuring bar evidently has a greater inherent potentiality for accuracy than most other systems, and hence it is not surprising to find that all four of the systems mentioned in this section were developed for, and have been applied to, jig borers. All are of Class 1 accuracy.

In metrology, the two basic forms of length standard are the line standard and the end standard. It is convenient to classify measuring-bar systems in numerical control into the same categories. Thus, the Fosdick and Schwartzkopff systems both use end standards, i.e., length bars (termed " gage rods " in the U.S.A.), whilst the B.T.H. and the Pratt and Whitney systems use the electronic equivalent of line standards, sensing being carried out electronically by an electromagnetic head, and not optically with a microscope, as in metrology.

Both the Fosdick and Schwartzkopff systems employ 10-station turrets for holding the length bars. The first turret holds bars of from 10 to 90 in. in length, in increments of 10 in. The second turret has bars from 1 to 9 in. in length, in increments of 1 in., while the succeeding turrets have bars with increments of 0·1, 0·01 in., and so on to the required degree of resolution.

Fig. 32. **Measuring bar of the B.T.H. system.**
(Courtesy of British Thomson-Houston Ltd.)

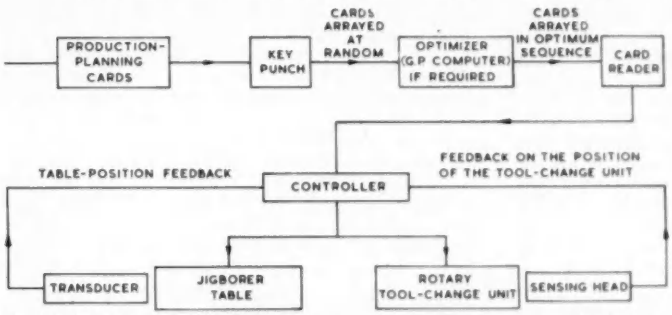

Fig. 30. **Block diagram of the Fosdick control system, using length bars as the measuring element.**

In the Fosdick system (which was developed in conjunction with the International Business Machines Corporation), the data are stored on IBM punched cards in conventional decimal form, and the card-reading unit is a type-407 IBM reader, modified to permit the information to be read column by column or all at once. This system is shown schematically in Fig. 30, from which it will be seen that a general-purpose computer may be used to optimize the sequence of cards. This is of assistance, since the Fosdick system is used (on the company's own jig borers) in conjunction with a 30-station rotary tool-storage unit (Fig. 31), and optimum efficiency is not necessarily obtained by drilling or boring all holes of the same diameter one after the other ; for example, if the holes are very scattered, it may be more efficient to change tools several times.

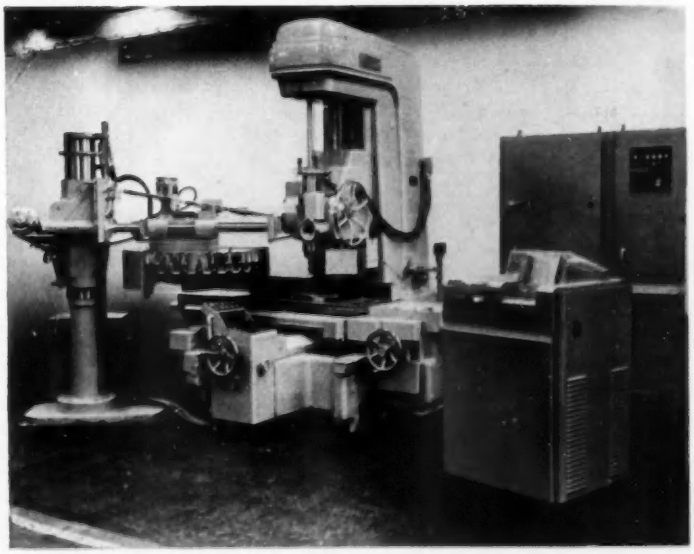

Fig. 31. **A Fosdick jig borer with (left) a 30-station rotary tool-storage unit.**
(Courtesy of Fosdick Machine Tool Co.)

The fact that the analogue-to-digital conversion is not effected at the machine-tool slides enables the Fosdick system to employ limit switches only in its feedback system. Each axis has a motor which drives the six switches required for the six significant digits from tens to ten-thousandths of an inch (Fig. 31), and the ten contacts of each switch are connected to the ten contacts of the corresponding digit of the card-reader; hence, for the " tens " figure, if the card is punched at 60, the sixth contact on the " tens " switch will be live. As the motor drives the arms of the switches, the " tens " arm will contact a live point at the sixth position, and

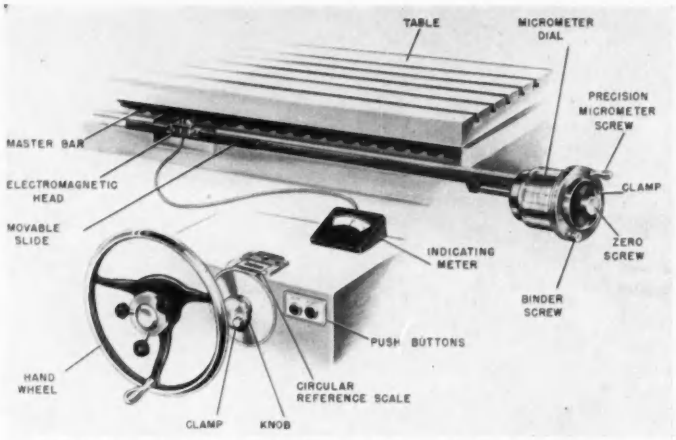

Fig. 33. **Measuring elements of the Pratt & Whitney system, showing the recessed or castellated measuring bar.**
(Courtesy of Pratt & Whitney Co. Inc.)

this will cause a " tens " clutch to drop out and the corresponding relay to operate, stopping the " tens " length-bar turret at the sixth position, i.e., it brings the 60-in. length bar into position.

This procedure is repeated until all six clutches have dropped out, and consequently until all six length-bar turrets have been brought to their correct positions. The table drive is now started, and a projecting lug on the table encounters the first of the length bars and pushes it along until all six bars are stacked end to end ; at this juncture, a limit switch stops the table drive. The table is then positioned, and the drilling (or other) operation can proceed.

The Schwartzkopff system, produced by Berliner Maschinenbau AG, is set manually by means of a plug board, but a mechanical aid is incorporated, enabling a large card to be punched on a desk machine in such a manner that the operator has only to fit the card over the plug board and insert plugs where there are holes ; in other words, the operator is not obliged to understand the functioning of the plug board. It is interesting to note that the measuring system is made under licence from a British firm, the Newall Engineering Company.

The measuring bar of the B.T.H. system (Fig. 32) is of heavy construction and carries enough " inch " units to cover the table movement. Each " inch " unit is a 1-in. steel block with a $\frac{3}{8}$-in. diameter hole drilled through it, and, in order to provide a continuous surface, the holes are filled with brass inserts, which are non-magnetic. The bar is produced in a temperature-controlled room with the reference holes 1·0000 $\pm$ 0·0002 in. apart. A final screwdriver adjustment is available, which alters the position of an asymmetrical steel slug in the bar, this operation preferably being performed *in situ*.

In the Pratt & Whitney system, the master measuring bar derives its 1-in. spacing by milling out and grinding a series of $\frac{1}{2}$-in. recesses at a 1-in. pitch (Fig. 33), the cumulative error being only 0·00002 in. The bar is supported throughout its whole length in a dovetail guide and is fixed at one end only. The Pratt & Whitney Company

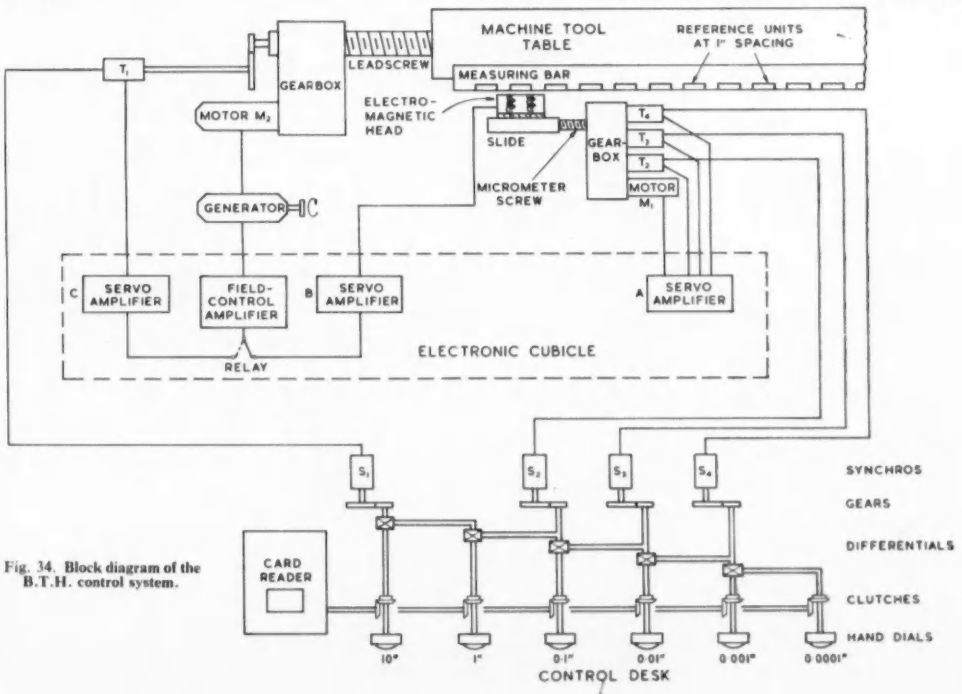

Fig. 34. **Block diagram of the B.T.H. control system.**

Fig. 35. **Control desk of the B.T.H. positioning system.**
(Courtesy of British Thomson-Houston Ltd.)

feels that it can develop a master measuring bar of greater accuracy than that of existing optical systems.

In both systems, location to the nearest inch is achieved by means of the measuring bar and an electromagnetic head which generates an electrical voltage providing a misalignment signal to the control system, until it is aligned with the centre of one of the brass inserts (B.T.H.) or castellations (Pratt & Whitney). In both systems, the decimal or fractional parts of an inch are obtained by moving the sensing head along its precision micrometer screw by the desired fraction. For example, if a movement to the left of 16·8735 in. is required, the main drive moves the table through a distance of 16 in. to the left ; meanwhile, the sensing head is moved 0·8735 in. to the left along its micrometer screw, and thus the table has to move a further 0·8735 in. before alignment between the measuring bar and the sensing head is achieved. When this alignment is realized, the table stops.

Fig. 34 shows a block diagram of the B.T.H. system, while Fig. 35 is a photograph of the control desk. At the lower left-hand corner of this desk is the reader for the punched cards, which are of untearable material and are punched in a small hand machine, using conventional decimal coding. As an alternative, the two co-ordinates, i.e., the table and the spindle slide, may be set up by the two rows of six decade switches seen at the lower right of the control desk, but, in either case, the information enters the system via the decade switches; the method can be reversed, so that the machine tool acts as a two-co-ordinate measuring machine, the switch dials indicating the amount of table movement.

In the B.T.H. system, when the required co-ordinate has been set up on the six dials (Fig. 34), the input synchros S_1, S_2, S_3, and S_4 are rotated through suitable gearing and give misalignment signals in co-operation with the corresponding output synchros T_1, T_2, T_3, and T_4. The " decimal " dimension is defined by shaft rotation of S_2, S_3, and S_4, which causes the servo-amplifier A to operate motor M_1, until S_2-T_2, S_3-T_3, and S_4-T_4 are in alignment. An accurate micrometer screw shifts the electromagnetic unit via gearing through the required " decimal " dimension.

The " integral-inches " part of the desired co-ordinate (with a contribution from the decimal part) gives a rotation of synchro S_1 which is interconnected with synchro T_1 geared to the leadscrew. A misalignment signal from S_1-T_1 controls servo-amplifier C, and, by means of motor M_2, brings the table to within about 0·2 in. of the desired position, the traverse speed being maintained at about 120 ipm until the last inch or so of travel is reached, after which the speed is progressively reduced. Control of M_2 is now transferred (via servo-amplifier B) to the electromagnetic head. The control signal from the latter drives M_2 until the poles of the magnetic head are aligned opposite the nearest hole in the bar.

The B.T.H. system has been applied principally to Newall jig-boring machines and to Kearns horizontal boring machines. Fig. 36 shows a Kearns No. 0 horizontal boring machine, with a planer-type table, equipped with B.T.H. positional control. This machine has been in service for some time at the Leicester factory of the British United Shoe Machinery Company Limited.

A block diagram of the Pratt & Whitney system is shown in Fig. 37, from which it will be noted that the information is supplied by means of punched tape. This tape is decimally coded, since the company feels that the operator should be able to read information from the tape, if he so desires. As in the B.T.H. system, the co-ordinates can be set up manually by means of decade switches (visible on the desk in the foreground of Fig. 38).

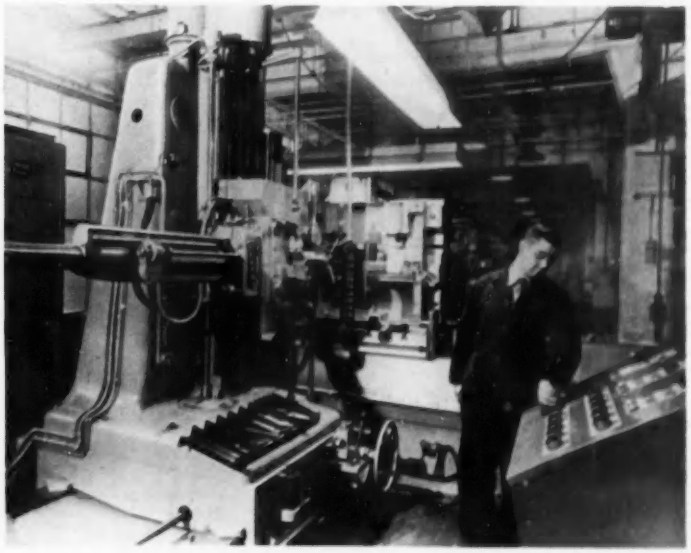

Fig. 36. **The B.T.H. positional-control system applied to a Kearns horizontal boring machine.**
(Courtesy of British Thomson-Houston Ltd.)

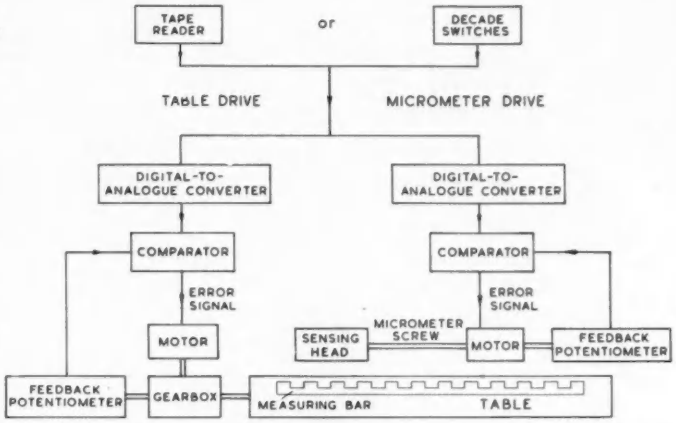

Fig. 37. **Block diagram of the Pratt & Whitney positioning system.**

In the Pratt & Whitney system, there is a digital-to-analogue conversion for both coarse and fine positioning, and the angular rotations of the table leadscrew and the sensing-head leadscrew are fed back from potentiometers. For fine positioning the analogue voltage of the decimal fraction of the inch is compared with the voltage fed back from the potentiometer on the micrometer leadscrew, any error voltage actuating the servo-motor which drives the micrometer leadscrew. To reduce the effects of backlash, final positioning of the table is always effected in the same direction, the velocity variation being as shown in Fig. 39. To accomplish the overshoot required when positioning from right to left, an extra voltage is added to the analogue voltage for the distance to be moved. Within 0·25 in. from the set point, the cycle of velocity variation is the same for positioning from either direction.

Systems using Optical or Diffraction Gratings

The oldest system using optical or diffraction gratings is the Ferranti system, which is, however, fundamentally a continuous contour system and is not ideally convenient for indiscriminate use for either positional or continuous contour control. The situation is largely that the Ferranti Company is prepared to develop a special positional control variation of the system, but it has invested a considerable amount of capital in developing numerical control (as much as any company and more than most), and it prefers to be reasonably certain of the interest in this field before burdening the financial side of the development programme even more heavily.

The measuring element for identifying the table position is a diffraction grating carrying a known number of lines per linear inch (usually from 500 to 2500, depending on accuracy), the lines being perpendicular to the length of the grating. When two sections of such a grating are superimposed with a very small angle of mutual inclination, a moiré fringe pattern is produced, as shown in Fig. 40. The distribution of intensity of this pattern is approximately sinusoidal, and the system is effectively a method of magnifying the spacing of the lines on the grating.

If one grating moves longitudinally relative to the other, the fringe pattern moves at right angles to the direction of relative movement in a sense uniquely associated with that of the relative movement. The basis of the measuring element is a photo-electric cell, which " observes " a small stationary area of the fringe pattern and generates pulses of electricity as the pattern moves across the observation area, thereby creating alternations of light and darkness.

Fig. 38. **The Pratt & Whitney system applied to one of their jig borers.** *(Courtesy of Pratt & Whitney Co. Inc.)*

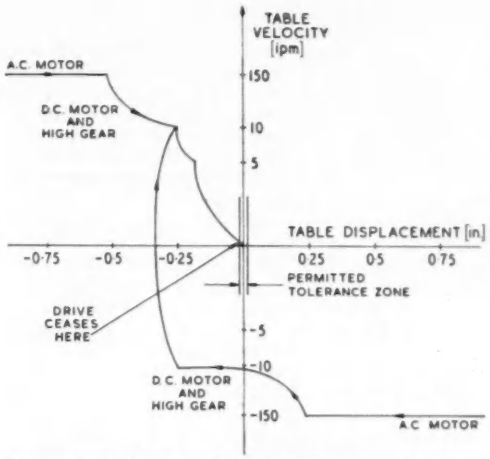

Fig. 39. Graphical representation of the final positioning of the moving member in the Pratt & Whitney system.

In order to discriminate direction, the system actually observes two points in the fringe pattern which are an odd number of quarter wavelengths apart, i.e., 90 electrical degrees. This produces a two-phase system which discriminates direction in the manner already described. The standard gratings have 500, 2500, and 5000 lines per inch and give resolutions of 0·001 in., 0·0002 in., and 0·0001 in., since the measuring system gives rise to two

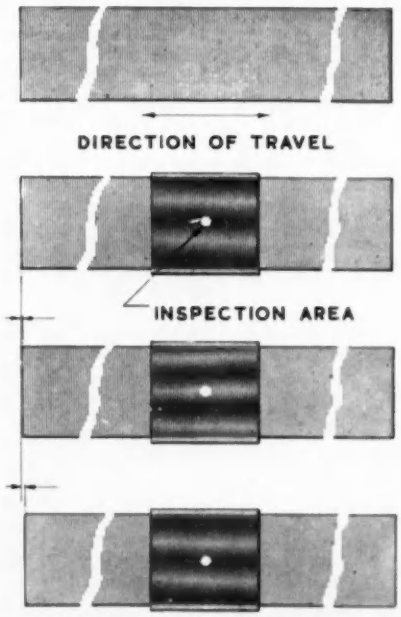

Fig. 40. Formation of moiré fringe patterns.

electrical impulses per band—one when the brightness has increased beyond the threshold value, and the other when it has decreased below the threshold value.

The system employs a d.c. amplifier but, although d.c. amplifiers are more troubled with drift than a.c. amplifiers, Ferranti have not found that their use gives rise to problems of any magnitude. The reason for the large number of lines per inch on the gratings is that resolution is not significantly greater than the line spacing and, as a d.c. system is used, frequency multiplication cannot be employed to improve resolution.

In England, the Brush Electrical Engineering Company Limited has developed a system using diffraction gratings, in which a d.c. amplifier is not required and, by means of frequency multiplication, can give a resolution considerably finer than the spacing of the lines ruled on the grating. This system employs three gratings, one of which is ruled around the periphery of a drum, which is driven at a constant angular velocity ω.

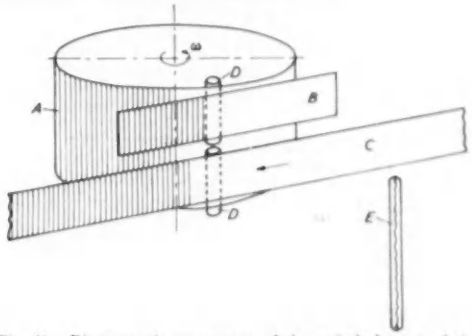

Fig. 41. Diagrammatic arrangement of the optical elements of the Brush positioning system.

Fig. 41 shows the arrangement diagrammatically. The rotating drum *A* is slightly longer (axially) than the combined width of the two linear gratings *B* and *C*. Grating *B* is only a few inches long and is fixed relative to the drum, while grating *C* has a length slightly greater than the traverse to be controlled and moves relative to the drum ; for example, grating *C* might be attached along the edge of the machine table, in which case the rotating drum *A* and grating *B* assembly would be the fixed member. As in any moiré fringe system, the three gratings have a slight mutual inclination, and a source of light *E* is provided ; however, in the Brush system, two photo-diode units *D* are required, since there are two fringe patterns to be counted.

The light passing through grating *B* forms a fringe pattern at the point of tangency with the drum, the frequency of fringes being determined by the peripheral velocity of the drum and the spacing of lines in the gratings. As a result, approximately sinusoidal voltage output from the photo-diode is produced and is regarded as the reference voltage. The fringe pattern produced by grating *C* also causes its photo-diode to give a sinusoidal voltage output but, as soon as the table begins to move, this voltage gradually moves out of phase with the reference voltage, being one complete cycle out of phase after a relative movement virtually equal to the spacing of the diffraction lines.

The control unit is fed with the two output voltages from the two photo-diodes in the measuring head, as shown in Fig. 42. These voltages require amplification and squaring, i.e., the sinusoidal shape must be converted to a square shape. The voltage from the photo-diode corresponding to grating *C* in Fig. 41 is then passed through an electronic differentiating circuit which thus produces pulses (of opposite sign) at the front and rear ends of each square wave. The reference voltage, i.e., that from the diode corresponding to grating *B*, is passed

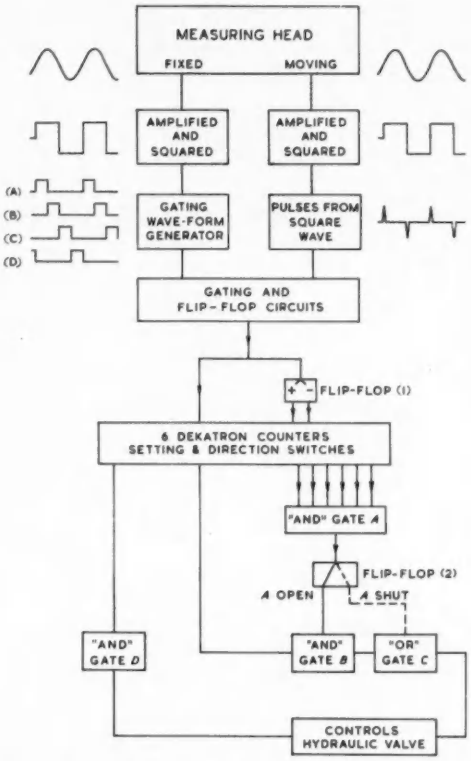

Fig. 42. Block diagram of the Brush system of positional control

through a "gating wave-form generator", which electronically produces four square-wave pulses (A), (B), (C), and (D) (at 90 deg. intervals) for each cycle, in effect doubling the resolution of the system.

These two signals are now fed to a circuit of flip-flops and "OR" and "AND" gates, whose effect is to produce an output of pulses in which one positive or negative pulse represents a unit of positive or negative movement. Incidentally, it should be understood that an electronic gate is somewhat similar to a hydraulic valve in that it may have two or more input lines *x*, *y*, *z*, etc. and a single output line. An "AND" gate produces a signal on the output line if all the signals on the input lines are present simultaneously, i.e., *x* and *y* and *z*, etc. An "OR" gate produces a signal on the output line if either the *x* or *y* or *z*, etc. signal is present.

These pulses are fed to a panel having six dekatron counters, together with setting and direction switches. At the present stage of development, the co-ordinates are set by means of switches, but the extension to tape control is obviously possible.

Flip-flop (1) is operated by the sign of the pulses and, in this simple manner, the direction of movement is accounted for. The pulses, after passing to the counter unit, subtract continuously from the figure set up by the switches, and 10 digits (normally this will mean 0·010 in.) before the required position, the "AND" gate *A* opens, causing flip-flop (2) to open the "AND" gate *B* and to condition the "AND" gate *D*. Prior to this stage, flip-flop (2) has caused the "OR" gate *C* to pass a level voltage to the hydraulic control valve, but, when the "AND" gate *B* opens, a voltage which decreases in ten discrete steps is passed through the "OR" gate *C* to the hydraulic valve. These steps correspond to the 10 digits referred to above, and the table is thus brought gradually to rest. On the last digit, the "AND" gate *D* opens and feeds a signal to the hydraulic valve, which cancels any previous signal from the "OR" gate *C*, and the table stops moving.

Initially, the dekatrons are set to zero in the datum position, so that accurate positioning of the table before commencing a cycle of operations is not necessary. The system was developed to work in conjunction with a hydraulic control valve developed by the Gloster Aircraft Company and referred to previously [1].

The intention of the Brush Company was to develop a system of average resolution and accuracy, for which they consider there is a very big field, despite the general tendency to think only in terms of high accuracy for numerical control applications.

The Mullard Company also has a system using diffraction gratings, and this was developed for the "Matrix" No. 150 jig borer of the Coventry Gauge and Tool Company, shown with its control unit in Fig. 43. At the moment, the system has no closed loop, and the operator has to position the table manually, using the system as a precision indicator. However, it is not intended to market any units in this form, and development of a punched-card input system is almost complete.

The length standard for the system is a steel buttress scale, i.e., a solid steel bar having a sawtooth form cut into it at a pitch of 0·1 in. The maximum adjacent pitch

Fig. 43. The Mullard optical control system applied to a Coventry Gauge & Tool Co. "Matrix" jig borer.
(Courtesy of Mullard Equipment Ltd.)

error is 0·00002 in., and temperature effects are reduced by making the scale of the same material as the remainder of the machine.

The optical part of the system has to interpolate this 0·1-in. basic step with units of 0·0001 in. For this purpose, a glass scale is employed, with 1000 lines ruled over a distance of 2 in. By means of an optical lens system this is reduced in the ratio of 20:1, and the 1000 lines fit into an apparent distance of 0·1 in. Fig. 44 shows the two-dimensional system diagrammatically. The light from a common source is reflected by two 45-deg. mirrors through a scanner disc, whose object is to provide a beam of light, 0·001 in. in width, which scans the interpolation scales at a constant speed. The narrow width of beam is obtained by using four cylindrical rod lenses which are carried by the planet wheels of an epicyclic gear train, whose tooth numbers are so adjusted as to give no absolute rotation of the planet wheels. Thus, the interpolation scales are continuously scanned at a constant speed. These interpolation scales are the optical gratings referred to previously.

Where the narrow beam of light passes through a clear portion of the scale, it is transmitted via mirrors to the buttress scale and an edge-detecting photo-cell. Light interrupted by the opaque ruled lines is reflected to a pulse-detecting photo-cell. The edge-detecting photo-cell commands an electronic counter to count the pulses from the pulse-detecting photo-cell. This command, in effect, causes pulse-counting to be commenced at some integral multiple of 0·1-in., and thus the pulses correspond to the interpolation of the 0·1-in. basic subdivision. A comparison is made of the pulses counted with the number of ten-thousandths of an inch set up on the switches, and a display of seventeen lamps gives a visual indication of the error, the centre lamp of the seventeen corresponding to zero error.

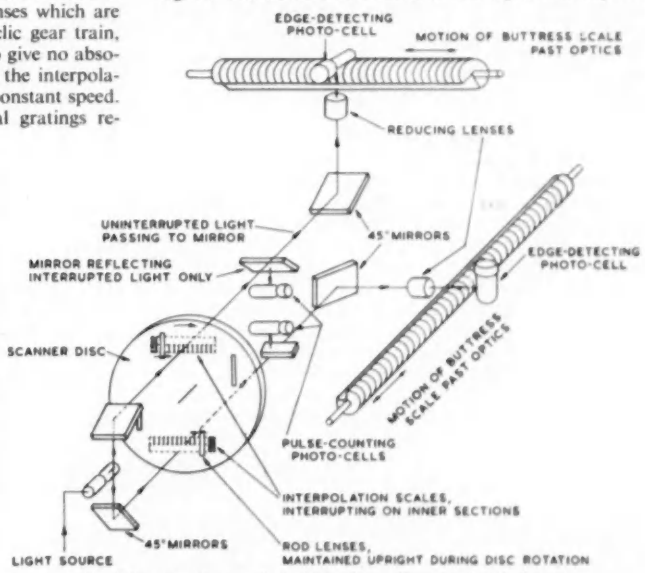

Fig. 44. Schematic diagram of the Mullard two-dimensional optical system.

Another firm entering the field of positional control is Ericsson Telephones Ltd., whose Instrument Division has developed a system of numerical control based on an optical pulse-counting technique, which does not require the use of diffraction gratings. Standard 5-channel punched tape is the storage medium, four channels being used for encoding the numerical information in pure binary form. It will be recalled that the only other system which uses pure binary coding for the input information is that of the Barnes Engineering Company and employs a 32-channel punched tape, 15 channels being reserved for the numerical information corresponding to each axis. The Ericsson system avoids this by reading a " block " of information consisting of 16 holes, i.e., four rows of the four columns marked (a) to (d) in Fig. 45, which shows a portion of an Ericsson tape. In this tape, the hole patterns for what are called the *X* and *Y* addresses are merely indications to the tape-reader that blocks of information concerning an *X* or *Y* co-ordinate are about to be read. The fifth channel (p), marked " parity bit column ", is used to check the correct reading of the tape and also the correct storage. Following the numerical information for a given point are any functional commands, such as " operate " and " datum ", for which a 2-out-of-5 or a 4-out-of-5 coding system is used, so as to provide a larger number of combinations than is possible with a 1-out-of-5 coding of the five columns.

The numerical commands pass to the controller, where they are compared with the information fed back from the transducer, which converts the linear or angular movement into a number of pulses, each pulse corresponding to a definite table movement. The distance represented by each pulse is, of course, the linear resolution of the system.

The company has developed a rotary pulse transducer giving 1000 pulses per revolution ; in conjunction with a 10-tpi leadscrew, this gives a resolution of 0·0001 in., but obviously the accuracy of the overall system, including the machine tool, would not be commensurate with this figure. An alternative method of sensing the table position is to drive the transducer through a precision rack and pinion, in which case a rather better accuracy for the same standard of manufacturing components would be obtained, but, with the present transducer, the linear resolution could not be better than about 0·004 in., owing to the limiting size of the pinion.

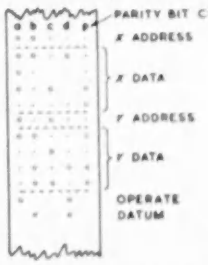

Fig. 45. Section of tape used in the Ericsson system of positional control.

Work is proceeding with the object of improving the angular resolution of the transducer. It should, however, be noted that, where a higher accuracy is required, the company proposes to sense table position directly by means of diffraction gratings, which are, of course, ideally suited to a system based on pulse-counting techniques.

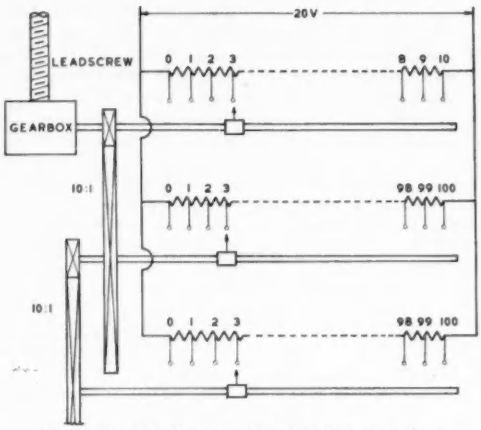

Fig. 46. The potentiometer system of the Wang control unit.

The Japanese Government Mechanical Laboratory is developing a system with coarse and fine transducers of an optical type. Coarse detection is effected by optically counting the graduations on a main scale, the spacing of these graduations being 0·040 in. Fine positioning is accomplished by counting moiré fringes generated by a diffraction-grating system mounted on an attachment to the main carriage and capable of detecting to 0·00004 in., with an accuracy of about twice this figure.

The information is fed to the control unit by means of 6-channel standard Japanese teleprinter tape. A 2-out-of-5 code is used for the punched holes, and a second tape gives instructions regarding the sequence of the holes coded in the co-ordinate tape.

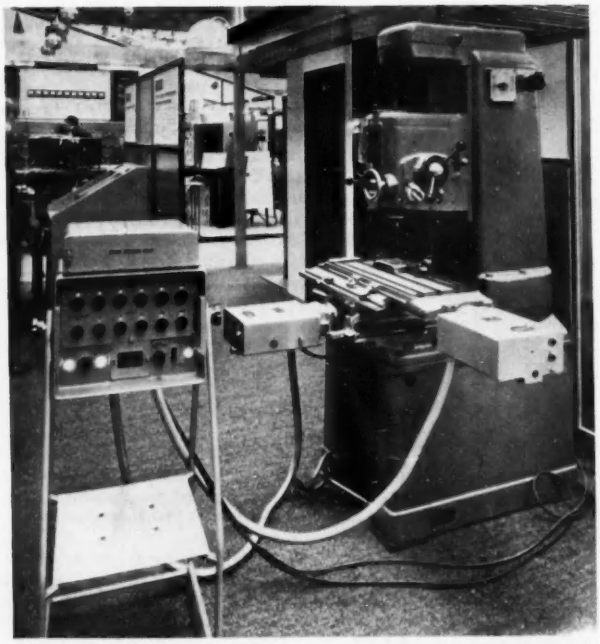

Fig. 47. The Ekco control system applied to a drilling machine, showing (left) the control panel, (centre) the transverse traverse unit, and (right) the longitudinal traverse unit. (*Courtesy of Ekco Electronics Ltd.*)

In this system, a hydraulic servo and an induction motor are used for coarse positioning of the *X* and *Y* axes respectively, whilst for both axes fine positioning is by d.c. shunt motors.

It will be appreciated that, if the anticipated accuracy is achieved, this will be one of the most accurate systems known, although experience with the well-tried Ferranti system, which also uses moiré fringes, would suggest that the design of the machine will have to be very carefully considered. The policy of the Brush Company with regard to accuracy has already been pointed out, but the other three systems described all give Class 1 accuracy.

Systems using Potentiometers

All systems employing potentiometers may be described as electrical, rather than electronic, and their accuracy is medium to high, i.e., Class 1 or 2.

No standard model of positional control system using potentiometers is produced by Wang Laboratories Inc., but this firm undertakes to develop systems to fit particular applications. The basis of these systems is a position-identifying device consisting of three potentiometer resistances, tapped and joined to three switch-decks with wipers coupled through gearing to the leadscrew, as shown in Fig. 46. The first switch-deck has 10 contacts and senses the tens figure, whilst the second deck has 100 contacts and senses the units and tenths of an inch figures, both decks effectively counting rotations of the leadscrew, which has a pitch of 0·1 in. The third deck also has 100 contacts and divides one leadscrew revolution into 100 parts, thus providing the hundredths and thousandths of an inch figures. The system is so designed that the output from the first deck overrides the outputs from the other decks until the table is positioned to the tens figure ; control later passes in a similar way from the second to the third deck.

The system marketed by the Reeves Instrument Company converts the digital information from 6-channel tape into voltage analogue form immediately after reading it. These voltages act as fine and coarse references and are compared with the output voltages from coarse and fine potentiometers, whose contact arms are driven by the table through a rack and pinion.

The error signal between the coarse reference voltage and that from the coarse transducer potentiometer operates a servo-motor which moves the table so as to reduce the error signal. When the error signal reaches a limiting (small) value, control is changed to the fine system. The fine transducer is actually an induction potentiometer having two windings and producing two separate output voltages at 90 deg. to one another ; it is not, however, a synchro, in the strict sense of the word, since its output voltages vary linearly with table position and thus do not provide a sine-cosine analogue.

The system produced by Ekco Electronics Ltd. employs a Wheatstone-bridge circuit in the control system. One arm of the bridge is a master tapped potentiometer, which is set, by means of knobs, to the desired measurement. These knobs and the number display can be seen on the control panel at the left of Fig. 47. The servo-head contains six potentiometers,

(known as slave potentiometers), three of which, corresponding to the three most significant digits, are driven through gearing from a large servo-motor, while the other three, corresponding to the three least significant digits, are driven from a small fine-positioning motor. These slave potentiometers are connected in a second arm of the bridge. The drive continues until the bridge is balanced, so that the bridge detector is effectively the comparator of the command and feedback voltages.

Development work is in hand to provide, in the form of punched cards, a permanent storage, which will be a separate unit that can be fitted to an existing manual control system.

Miscellaneous Systems

Under this heading are grouped various systems which, strictly speaking, do not fall into any of the previous categories. Thus, the Research Corporation of the Warner & Swasey Company has developed a system which is available in two forms, depending on whether the user wishes to connect the measuring head to the leadscrew (or other main drive) or to keep the measurement quite independent of the table drive. In the latter case, the measuring head carries a pilot slide which, by means of a ratchet and pawl, can be set accurately to integral multiples of one inch. The setting of the least significant figures is performed with the aid of a high-precision micrometer screw which is also tape-controlled.

The main drive is started and continues until final positioning is achieved by means of a sensitive limit-switch between the table and pilot slide. Given a suitable machine tool, this system will position to a high accuracy and, in fact, most of its applications have been to the more precise machine tools, such as jig borers and grinders.

The Jacy system of the Modern Engineering Service Company is applicable to single-axis rotary motion or to multi-axis linear motion. However, to date it has been applied only to rotary motion. The rotary table is integral with a high-precision worm-wheel, which is driven by a conjugate on the dual-lead principle. The worm has, in fact, a slightly different lead angle at the entrance portion of the thread than at the exit end, and thus the tooth form tapers slightly from one end to the other, automatically effecting a locking action when the table is stopped. In practice, the system is adjusted for zero backlash.

The drive shaft to the worm also carries a master index plate with four lobes accurately spaced at 90 deg. As each lobe passes a special electronic valve (known as a magnetron beam switching tube), an electrical pulse is produced and is fed to an electronic counter. Since one revolution of the worm corresponds to 4 minutes of arc of table movement, each pulse represents a table movement of 1 minute. Five decade counters record movements up to 360 deg. = 21,600 minutes, in steps of 1 minute. A unique feature of the system is that, on the last pulse, the system is mechanically locked in the correct position by energizing a shot-pin which locates the correct lobe of the master index plate and prevents any further motion.

A common operation in rotary-table work is to subdivide 360 deg. into a number of equal steps. Evidently, with a resolution as fine as 1 minute, many such operations could be carried out exactly, i.e., to the accuracy of the table and drive. However, certain numbers could occur (particularly prime numbers) which would need decimal subdivision of 1 minute and, indeed, might easily involve recurring decimals. Clearly, this system, as it stands, is limited to a 1-minute resolution, which, on each indexing movement, might not present a serious error but, when nearing its complete revolution, could give rise to a considerable cumulative error. To guard against this eventuality, the Jacy system has an extra counter in 0·1, 0·01, and 0·001 minute ; this counter does nothing to increase the resolution but prevents an accumulation of errors and continuously sums the error and decides whether the remainder is nearer to the preceding or succeeding minute of arc. This means that the table is always positioned to within ½ minute of arc, even though the resolution is only 1 minute of arc. The system is fail-safe from the point of view that, if the commanded and measured number of pulses do not agree, the table will lock, but no operation can be initiated.

In the systems described previously, the drive motor serves only the function of driving, a separate measuring and feedback system providing the "intelligence" to stop the motor at the required position. If, however, the motor could either incorporate the measuring system or render it unnecessary, then the feedback would not be required. There appears to be only one system operating in this manner—the Teller " Digitork " system, which employs a stepping motor operating from pulses, the rotor moving through a precise angle for each pulse passed. Thus, a command to move a certain distance is given as a number

Fig. 48. "Hydroptic" model 6A jig-boring machine with playback system.
(Courtesy of Société Genevoise d'Instruments de Physique)

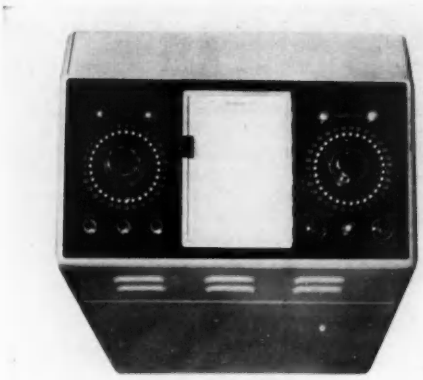

Fig. 49. **The control console of the Société Genevoise system.** (*Courtesy of Société Genevoise d'Instruments de Physique*)

of pulses which cause the rotor to move through the required angle in a number of increments equal to the number of pulses.

The motor has been fully described elsewhere [6] but brief details are given here. The stator of the motor is divided axially into three sections or phases. Each phase has 20 or 36 poles, depending on its power, and the poles of the three phases are aligned axially. Poles are wound so that alternate poles have opposite polarity. The rotors have the same number of poles as the stators and the same spacing, but overlap the poles of the preceding rotor by one-third of a pole width. By pulsing the three stator phases cyclically, in one direction or the other, the rotor is caused to turn in discrete intervals, either clockwise or anti-clockwise.

Information may be supplied to the unit either by decimally coded punched tape, or by means of a telephone dial. These two methods may be used individually (to give permanent or temporary storage) or together. If necessary, the telephone dial may be located in the production planning office.

In the preceding sections, mention has several times been made of numerically controlled jig-boring machines. The Société Genevoise d'Instruments de Physique, however, has decided that a playback or repeater system is best suited to the jig-boring machine, for which, they maintain, the services of a skilled operator cannot be dispensed with. The "automatic" jig borer is only automatic in that the *setting* of the co-ordinates is automatic ; suitable clamping of the workpiece without deformation, selection and adjustment of the cutting tools, and selection of cutting speeds and feeds are *not* automatic. In order to increase the overall operating efficiency, however, the company has made available a repeating device, or playback system, on their new "Hydroptic" machines, models 6A and 7A (Fig. 48). Co-ordinate setting is speeded up and repeatability, to the order of 0·00004 in., is better than that obtainable with a skilled operator. Although not a numerical control system, it has several interesting features, including an extremely fine position-identifying device, i.e., the photo-electric microscope which the company developed for dividing machines and the comparison of line standards, which will measure to an accuracy of 0·4 micro-inch.

The system is quite simple from an operational viewpoint. After completing setting of the table, with the aid of the usual S.G.I.P. standard scale and optical system, the operator then sets the table and spindle-head selector switches and presses the "record" button on the control console. As can be seen from Fig. 49, thirty different settings may be recorded, but this number can be increased quite considerably if several of the settings have one co-ordinate in common. Pressing the "record" button causes local magnetization of a very small area of the periphery of each of two magnetic-memory drums, one of which (the approximate memory drum) is used for coarse positioning, while the other (the micrometer memory drum) records the setting of the micrometer, providing, in effect, the command information when the subsequent components are produced.

Fig. 50 shows the variation of table or head saddle speed as the commanded position is approached. At about $\frac{3}{4}$ in. from the required position, the first slow-down occurs and position sensing begins. The photo-electric microscope has a limited discrimination and, to avoid ambiguity, two synchros are used for the coarse positioning ; during this period, the output of the coarse, and later the finer, synchro is compared with the command information from the approximate memory drum, thus producing an error signal which is amplified and used to control the table (or head saddle) traverse motor.

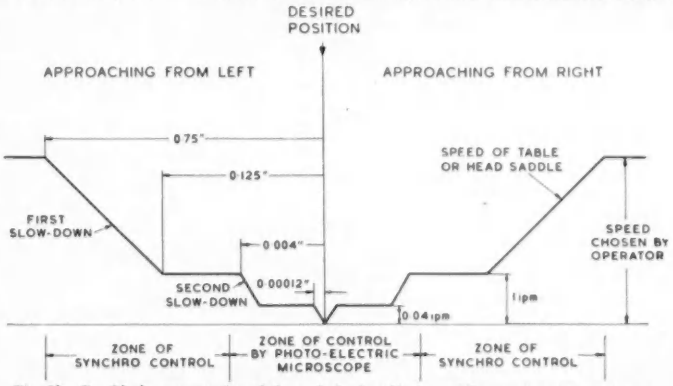

Fig. 50. **Graphical representation of the variation in table (or saddle) speed, during positioning with the Société Genevoise system.**

At approximately 0·02 in. from the position to be repeated, control passes from the synchro and approximate memory drum to the photo-electric microscope and micrometer memory drum. The photo-electric microscope senses an engraved line on the standard scale (which is attached to the table) and determines the amount of unbalance in the intensity of light which it receives. When the intensity of light is balanced, the microscope is aligned. About 0·0001 in. before the required position, the photo-electric microscope gives its last signal, causing a brake to stop the moving member. The delay time between the signal and the cessation of motion is not only very short but is also remarkably constant.

[6] A. G. Thomas and F. J. Fleischauer : "The Power Stepping Motor—A New Digital Actuator" ; *Control Engineering*, January 1957, page 74.

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THE ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

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High-Strength Non-Magnetic Alloys

By H. BERNSTEIN. (From *Materials in Design Engineering, U.S.A.*, Vol. 48, No. 2, August 1958, pp. 104–106, 2 illustrations.)

IN many applications, it is important that critical magnetic devices should not be magnetically affected by the materials used in nearby structures, equipment, and tools. A number of non-magnetic non-ferrous metals and stainless steels are available, but the strength and other mechanical properties of these materials are often inadequate. In many applications, there is a need for non-magnetic alloys with tensile strengths of about 200,000 psi, with approximately 5% elongation, and the alloys which come closest to achieving these values are discussed in this article.

ALLOYS CONTAINING COPPER

A beryllium-copper alloy containing 2% Be and 98% Cu can be used in applications where a non-magnetic material with moderate strength is required. The permeability of this alloy is 1·001, and it can attain a strength of 175,000 psi after standard heat treatment, and about 200,000 psi after cold-working and heat treatment, without altering permeability, but elongation averages less than 2%. Variations in heat treatment, intended to improve ductility, have not been successful.

The 2%Be/98%Cu alloy normally contains a small amount of iron impurities which largely determine its magnetic properties. The effects of iron on magnetic properties can be controlled by varying the solution-anneal temperature. For example, the permeability of beryllium-copper containing 0·5% iron by weight is over 1·01 after a normal solution-anneal at 1450°F. However, permeability is reduced to 1·001 after solution-annealing at 1550°F. After heat treatment, the magnetic properties of this alloy are relatively unaffected by short-time exposure to temperatures up to 900°F.

Somewhat higher strengths can be obtained with a beryllium-copper alloy containing 2·75% Be. Standard heat treatment has produced tensile strengths of over 200,000 psi, but, here again, the usefulness of the material is limited in high-strength applications by its low ductility.

Detrimental eddy-current effects have sometimes been encountered when using fairly large flat shapes of beryllium-copper. In such cases, materials with higher resistivity values, such as the copper-nickel-manganese and the titanium-aluminium-vanadium alloys, have proved to be acceptable substitutes.

An alloy containing 20% Cu, 20% Ni, and 60% Mn combines low permeability (about 1·002) with high strength and adequate ductility. Some forging difficulties have been encountered with large ingots, but the alloy hot- and cold-works easily in small sections. It offers no machining problems and is readily welded and soldered.

Unlike beryllium-copper, this alloy has a high magnetic tolerance for iron, and its magnetic properties are unaffected by heat treatment. Iron contents of up to 1% can be tolerated with no change in magnetic properties. The maximum tensile strength of the alloy varies from 200,000 to 215,000 psi, depending on the method of processing.

ALLOYS CONTAINING COBALT

The magnetic properties of "Elgiloy", an alloy containing 20% Co, 16% Cr, 15% Fe, 7% Ni, and 42% Mo, are generally satisfactory. However, for unknown reasons, these properties are variable and occasionally unacceptable. Permeability can vary from 1·003 to as high as 1·01.

This alloy is not heat-treatable, but by suitable processing it can be produced in tensile strengths ranging from 120,000 to 265,000 psi. It may readily be cold-worked, but is not amenable to press- or hammer-forging. Metal-cutting operations are difficult, but the material can be machined satisfactorily if the proper tools and practices are used.

"Haynes 25", an alloy containing 20% Co, 15% Cr, 10% W, and 55% Ni, can be used in either the annealed or cold-worked and age-hardened condition, and has a magnetic permeability of 1·001 in all tempers. This alloy has a tensile strength of 150,000 psi and an elongation of 60% after annealing. Tensile strengths up to 320,000 psi and an elongation of 2%, are obtained after cold-rolling (50% reduction) and ageing. The material is particularly useful in applications where localized areas of high hardness are required.

TITANIUM ALLOYS

Titanium alloys have excellent non-magnetic properties because of their paramagnetic characteristics. Thus, a titanium alloy containing 2% Al and 2% Fe has a permeability of less than 1·001 in all tempers, with negligible remanence. This alloy can develop tensile strengths up to 200,000 psi by suitable heat treatment.

Despite these advantages, the use of titanium in non-magnetic applications has been held back by its comparatively high cost and by fabrication problems. These objections may be overcome in the future, but at the present time the material is not too popular for non-magnetic uses.

STAINLESS STEELS

In an annealed temper, type 304 stainless steel (18–20% Cr, 8–11% Ni) has low permeability and remanence. However, its strength is comparatively low (75,000 psi). Since this alloy does not respond to heat treatment, its strength can only be raised by cold-working, which unfortunately produces a phase change in the material and increases permeability. Thus, the permeability of the alloy in the annealed state is about 1·003, but rises to 1·10 after 10% cold-working.

(Concluded on page 412)

U. S. A.

The Machining Characteristics of Beryllium

By D. R. WALKER. (From *Mechanical Engineering*, Vol. 80, No. 8, August 1958, pp. 57–62, 11 illustrations.)

EXHIBITING an elastic modulus 40% higher than that of steel, a strength/weight ratio 30% greater than that of titanium, a density comparable with that of magnesium, electrical and thermal conductivities roughly 40% those of copper, and a relatively high melting point of 2345°F, beryllium is a metal possessing a remarkable combination of properties. In fact, beryllium, which is currently used in X-ray windows, neutron sources, and moderators, and as an alloying element in copper, may well become an important structural material for aircraft and related applications, if problems connected with its high cost and lack of ductility can be solved.

Although beryllium can readily be machined, special precautions and procedures must be observed to prevent health hazards caused by the toxicity of the metal and its compounds. Wherever possible, the use of cutting fluids should be avoided, so as to permit easy collection and evacuation of chips by a vacuum system and to prevent contamination and devaluation of the chips as scrap material.

Beryllium-machining chips are generally partially continuous, consisting of discontinuous segments which reweld to each other after separation. The chips are thus extremely brittle and easily broken. When machining is effected at extremely high or very low speeds, or when tools having low or negative rake angles are used, chips are sometimes completely discontinuous.

The side of the chip which has been in contact with the tool does not have the burnished, shiny appearance found when cutting many conventional materials, but is instead extremely rough and contains many cracks. This rough surface is caused by a stick-slip phenomenon and the periodic formation and breakdown of a built-up edge on the tool point. At speeds above about 300 sfpm, the tendency to the formation of built-up edges diminishes, and the surface finish of both the work and the chip improves.

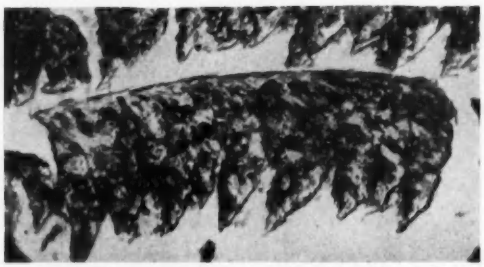


Fig. 1. Photomicrograph of a typical beryllium chip. (×75)

Photomicrographs of typical beryllium chips show that chip formation is primarily a brittle process. Fig. 1 is a photomicrograph of a chip from beryllium machined at 140 sfpm with a high-speed steel tool, using a feed of 0·0104 in. and a depth of cut of 0·100 in. Many partially rewelded cracks can be seen, together with some plastic flow and twinning, particularly on the sides of the chips that were in contact with the tools. Roughness produced by stick-slip motion of the chip along the tool face is also evident.

In general, machined beryllium surfaces improve in appearance and in smoothness with increasing tool rake angle. Rockwell hardness tests made on machined surfaces show no significant variations with tool rake angle or depth of cut.

Turning cuts have been made at depths as high as 0·100 in. and with feeds as high as 0·015 in. Tungsten-carbide tools having side rake angles as high as + 20 deg. and high-speed steel tools with side rakes up to + 35 deg. have been used without tool chipping. Cutting conditions appear to improve steadily with increasing rake angle. Carbide tools have been operated for short times at speeds up to 1000 sfpm, and high-speed steel tools have been used at speeds as high as 300 sfpm without immediate failure. Ceramic tools of standard negative-rake geometry have also been used successfully.

PHOTOGRAPHIC STUDIES OF THE CUTTING PROCESS

A motion-picture study of extremely-slow-speed beryllium machining has been made, using a milling machine to achieve a planing action, with cutting speeds of less than 2 ipm. Cutting phenomena were recorded as functions of tool rake angle, depth of cut, and cutting fluid.

These films show that chip formation was discontinuous, but that chip segments tended to stick together to form a partially continuous chip. Chips were formed partly by conventional plastic shear but mostly by a brittle-type splitting action. Surface crack formation was observed. Friction between chip and tool appeared high at the low speeds used, and a stick-slip action was seen. Frequent formation, destruction, and reformation of a built-up edge were evident, as was the effect of such a built-up edge on chip formation and surface finish. The use of high rake angles and low depths of cut was seen to improve the cutting action and resultant surface finish. Carbon tetrachloride as a cutting fluid seemed to have little or no effect on the cutting process.

In addition, a photographic analysis of beryllium machining at normal speeds has been made, using a still camera and spark illumination. The camera and light source were mounted on the cross-slide of a lathe and moved with a tungsten-carbide tool, as the latter was fed radially into a 3-in. diameter "spool" of beryllium.

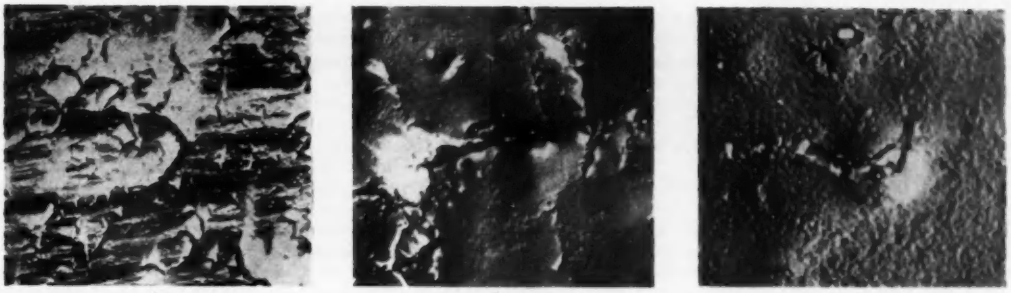
These photographs of the behaviour of beryllium at normal machining speeds (50 to 600 sfpm) showed substantially the same phenomena as those noted in the motion-picture studies of slow-speed machining. Completely plastic, continuous chip formation was not observed in the range of speeds used.

SURFACE DAMAGE BY MACHINING

An investigation has been made to determine the influence of machining depth of cut on surface damage. In this connection, it had been reported that surface cracks, approximately equal to the depth of cut, were caused by machining operations on beryllium, and it was considered possible that such cracks, formed by a roughing-type operation using a larger depth of cut, might propagate to greater depths if subsequent operations of comparable severity were used.

A specimen surface was produced on QMV beryllium,* using a conservative "safe" procedure, consisting of consecutive passes of decreasing severity, having depths of 0·124 in. (using a "step" tool with 0·062-in. steps),

* Beryllium produced by a proprietary powder-metallurgical process.



(a) (b) (c)

Fig. 2. Electron photomicrographs of a machined beryllium surface, (a) as-machined, (b) after chemical removal of 0·001 in., and (c) after chemical removal of 0·002 in. (×1700)

0·062, 0·032, 0·015, 0·010, 0·005, and 0·002 in. A second specimen surface was prepared by a far more severe procedure which used a depth of 0·186 in. (using a step tool with 0·062-in. steps and accompanied by severe tool chatter) followed by finish cuts having depths of 0·005 and 0·002 in. However, low-power optical microscopy (up to ×45) and fluorescent dye-penetration inspection did not reveal surface cracking on either specimen or any important differences in surface characteristics.

Examination under the electron microscope of the two specimens in the as-machined state (Fig. 2a) revealed numerous surface cracks in both cases but no significant difference in their number or apparent severity. Further examination of the specimens after chemical removal of 0·001 in. from the machined surfaces (Fig. 2b), using a solution consisting of 6·6% by weight CrO_3, 76·1% H_3PO_4, 5·5% H_2SO_4, and 11·8% H_2O, produced similar results. However, chemical removal of a total of 0·002 in. from the machined surface (Fig. 2c) eliminated the cracks on both specimens, thus indicating that surface cracks were not of depths comparable with the depth of cut in heavy cuts, and that a slow, safe machining procedure was unnecessary.

Beryllium Oxide Content of Chips

The beryllium oxide content of beryllium-machining scrap affects the value of the scrap for reworking purposes. To determine the influence of tool geometry and cutting speed on the increase in beryllium oxide content of QMV beryllium scrap, a series of chip specimens was obtained, using a tungsten-carbide tool, a depth of cut of 0·100 in., and a feed of 0·005 in./rev.

It was found that the average content of beryllium oxide of all samples tested was 1·37%, as compared with the original content of 1·27% before machining. The tests indicated that the beryllium oxide content of cutting chips was not a strong function of either cutting speed or tool geometry, and that machining increased the oxide content of QMV beryllium by not more than 0·2%.

Cutting Temperatures

The average temperature at the chip-tool interface during machining was measured by using a tungsten-carbide tool and the beryllium chip as the two dissimilar metals of a thermocouple. Temperature measurements were made as functions of cutting speed and cutting feed in a turning operation. The tool was insulated electrically from the lathe and was connected to one terminal of a recording oscillograph. A second lead was connected to the workpiece and thence to the oscillograph through a mercury commutator.

Fig. 3 is a plot of chip-tool temperature as a function of cutting speed at a feed of 0·006 in., while Fig. 4 shows the variation of temperature with feed at a constant speed of 350 sfpm, in both cases using a tungsten-carbide tool. As in machining most materials, cutting temperature is much more strongly dependent on cutting speed than on feed.

Tool-chip temperature strongly affects tool life, especially at high temperatures, since tool wear is accelerated with the decrease in tool hardness which accompanies increasing temperature.

Tool Life

The life of tungsten-carbide tools in machining QMV beryllium has been evaluated as a function of cutting speed and feed for finish-type cuts, using feeds less than 0·010 in. Tool wear is usually determined by measuring the rate of growth of the flat or land which is generated on the clearance or flank face of the tool. Tool life generally is defined as the time required to produce a

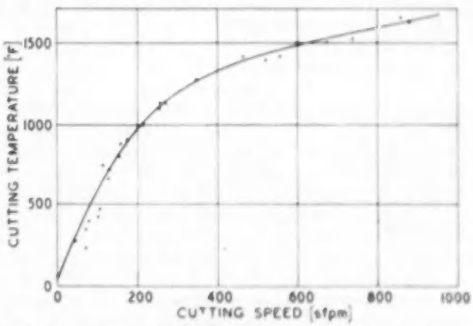


Fig. 3. Temperature of chip-tool interface as a function of cutting speed, with a constant feed of 0·006 in.

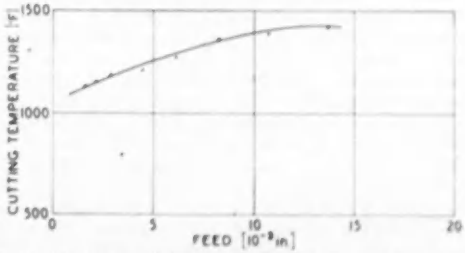


Fig. 4. Temperature of chip-tool interface as a function of feed, at a constant speed of 350 sfpm.

wear land of a given width. In the tests, wear lands of 0·010 and 0·015 in. were used as tool-life criteria.

The wear land on the clearance face of tungsten-carbide tools grows quite regularly and uniformly in beryllium machining. Wear of the cutting or rake face of the tools (cratering) is not severe.

Metal-cutting wear data can usually be made to fit the empirical relationship

$$VT^A = B,$$

where V is the cutting speed [sfpm], T is the tool life [min], and A and B are constants.

From the results of the tests carried out, on the basis of a wear land of 0·010 in. and the use of Carboloy 44A tungsten-carbide tools, the above relation was

$$VT^{0.18} = 680$$

With a wear land of 0·015 in. used as a definition of tool wear, the constant B in the equation becomes 770. Preliminary wear data obtained with Carboloy 883 tools (a harder, more wear-resistant grade of tungsten carbide) indicate that the constant A in the equation remains unchanged, while B becomes 760 for a tool life defined by an 0·010-in. wear-land life, or 860 for an 0·015-in. wear-land life.

Sufficient data for high-speed-steel tools have not been obtained to permit determination of the tool-life/speed relationship, but cutting speeds above about 100 sfpm appear to give limited tool life. Ceramic tool life has not been measured, but should be extremely good.

Representative tool-life data for the machining of beryllium (0·015-in. wear land), as compared with other materials, indicate that the life of tungsten carbide tools in beryllium machining is comparable with that found in machining low- and medium-carbon steels, and much greater than that in machining titanium and its alloys.

CZECHOSLOVAKIA

The Mechanism of Degradation of Titanate Dielectrics

By A. KOLLER and Z. POSPISIL. (From *Czechoslovak Journal of Physics*, Vol. 8, No. 3, 1958, pp. 315–321, 3 illustrations.)

In this article, details are given of the processes taking place in dielectric titanates when permanently subjected to direct voltages. Existing theories are discounted, and an interpretation of the mechanism of degradation is given, based on the production of colour centres.

IT is well known that condensers made of ceramic materials based on titanium compounds are indispensable parts of communications engineering. It is also known, however, that, in addition to a number of very advantageous properties, these dielectrics have one very unfortunate drawback, i.e., permanent direct voltage causes them to have a tendency towards so-called degradation, so that they lose their insulation resistance, become semiconducting, and break down.

This defect has been noted with dielectrics based on barium and strontium titanates with a high dielectric constant, and has led to breakdown of about 1% of such condensers before their minimum required life of from 5000 to 10,000 hours. It has also been observed that condensers subjected to long loading periods can exhibit blackening of the dielectric, either throughout the material or at least in several parts, and a deterioration in the insulation resistance and loss factor, even before breakdown. By refiring to a temperature of 800 to 1000°C, all the properties of the dielectric are regenerated.

The tendency of titanium compounds to reduce to a compound having a lower valency in a medium containing a reducing component or deficient in oxygen has long been known. Trivalent titanium contains an extra electron which is only loosely bound, so that it easily passes into the conductivity band. A similar result is obtained when the mass at the base of the titanium compound contains ions of higher valency than 4 as impurities in the lattice positions, and the electron neutrality must be balanced by a decrease in the valency of the titanium ion. These theories, however, have not been able to explain the mechanism of degradation as a result of long-term direct loading.

The most probable interpretation has, in the past, been that of Weyl and Terhune,* who suggested that degradation is caused by a hydrogen ion produced by electrolysis of the aqueous film which is always present on the surface of a ceramic; on account of its small dimensions, the ion easily penetrates as a result of the direct electric field into the interstitial positions of the crystals of titanates, where it then causes electrical non-equilibrium and thus also a decrease in the valency of titanium in the same way as an impurity of higher valency in the lattice position. This theory also assumes that Fe^{4+} occurs in titanate materials, protecting them against reduction, since Fe^{4+} first reduces to Fe^{3+} (which has no conducting electron). This theory accounts for a number of processes which can occur in the material, but, as far as the authors have been able to ascertain, it was created purely speculatively and has not been supported by any experiments.

* W. A. WEYL and N. A. TERHUNE: *Ceramic Age*, Vol. 62, No. 2, 1953, page 23.

EXPERIMENTAL INVESTIGATIONS

To investigate the mechanism of the degradation of titanate dielectrics, experiments were carried out on samples of two types of polycrystalline dielectrics. One of these materials, called rutilite, is basically polycrystalline rutile containing about 5% of different mineralizing and other admixtures. The second material, here designated VDT, is basically a mixture of barium titanate and strontium titanate. Degradation occurs with both materials and is accompanied by essentially the same phenomena.

The samples were mostly in the form of small plates, about 30 mm in diameter and 3 mm thick, prepared by dry compression. Firing, the temperature of which for both materials lies between 1300 and 1400°C, was carried out in an electric resistance furnace, without special treatment of the atmosphere. Experiments with degradation at higher temperatures were carried out in laboratory resistance furnaces. The gradient of the electric field applied to the plates during these experiments fluctuated between 0·5 and 3 kV/cm, according to the temperature and dielectric strength of the materials.

Since the processes investigated have so far not been

extensively studied experimentally and suitable methods have not yet been elaborated, most of the experiments were carried out for purposes of orientation and gave qualitative results only.

Influence of Adsorbed Water :—

Experiments were conducted to verify Weyl's interpretation of degradation as the effect of an aqueous film. In this connection, it will be appreciated that, if this interpretation is correct, an increase in temperature should eliminate the water from the surface, and the process would thus slow down or stop. On the contrary, however, as has been confirmed by other investigators, it was found that, with an increase in temperature, degradation caused by direct load was greatly accelerated, and at a temperature of about 350°C took place about three orders more rapidly than at room temperature. Changes in the material occurred at this rate, even when the sample had been previously heated for several hours to a temperature of 650°C and the experiment carried out at 350°C without first cooling to normal temperature.

Influence of Electrodes :—

The possible influence of the metal forming the electrodes has been partly taken into consideration in previous attempts at explaining degradation. In some papers, it has been experimentally shown that silver from the electrodes is transported by the electrical field into the material and influences its electrical properties.

The present experiments were confined to ascertaining that the presence of silver electrodes is not an essential condition of degradation, as similar indications of degradation were found when using aluminium, platinum, and even graphite electrodes.

Influence of Chemical Action on Degradation :—

If it is assumed that changes in the material occurring as a result of a direct electric field are, from a chemical point of view, caused by the reduction of titanates to suboxidic compounds, then this reaction should be accompanied by a loss in oxygen and thus a decrease in the mass of the samples. Experiments were carried out by weighing samples of about 8 grams, before and after degradation, by a direct load, as well as after reoxidation by firing to a temperature of about 800°C with access of air. At the same time, continual recording of weight changes was made by thermogravimetric analysis to an accuracy of 0·1 milligram. In none of these experiments was there found any change in the weight of the samples which departed from the limits of experimental error.

Similar measurements were carried out with samples of rutilite and permitite fired to 1260°C in a nitrogen atmosphere with 10% hydrogen, i.e., in the complete absence of oxygen. After firing, the samples had a dark-blue colour, which again became light-yellow by annealing to 1000°C with a sufficient access of air. After oxidation firing, an increase in weight of from 0·05 to 0·08% was found.

Colour Changes Accompanying Degradation :—

A characteristic of degradation is the change in colour of the dielectric, an originally yellowish shard becoming greyish-blue. This change does not, however, take place in the same way with all kinds of materials, and is particularly interesting in the case of materials of polycrystalline rutile. Apart from a layer of unbroken colour at the negative electrode, strongly coloured cones are formed, which have their peak at the cathode, and have a more lightly coloured base at the positive electrode. Their peaks lie in points which, even before applying the electrodes, were found to differ from the rest of the surface of the dielectric by their darker colour. These points probably contain as-yet unknown impurities which accelerate degradation.

Electrical Effect of Temperature on the Resistance of Degraded Dielectrics:—

Curves showing the dependence of electrical resistance R (expressed as log R) on absolute temperature T (expressed as $1/T$) are given in Fig. 1 for different samples of the VDT material. All these curves have a typical basic shape, already noted in the case of similar types of semiconductors. It is clear from Fig. 1 that, at room temperature, the resistances of degraded and perfect dielectrics are nearly equal. However, in the case of the degraded dielectric (curve (2)), the steep downward slope is initiated at a much lower temperature, so that, in the region around 480°K, the resistance of the degraded dielectric is very much less than that of a VDT condenser fired under normal conditions in an electric furnace (curve (1)) or of a sample fired in an oxygen atmosphere (curve (4)). After refiring the degraded sample in air at 800°C (curve (3)), the curve conforms to the original curve of a material before degradation (curve (1)). All these experiments were carried out on the same sample.

From the above results, it can be seen that the firing atmosphere, especially the partial pressure of the oxygen, influences the value of the internal resistance and its temperature dependence. Even more important is the fact, as evinced by the present experiments, that the method of firing also has a substantial effect on the intensity of degradation in the electric field. It was found that a dielectric fired in an electric furnace in an atmosphere enriched with oxygen exhibited no tendency to degradation or only to a very slight degree, while samples fired in a gas furnace, where the partial pressure of oxygen was smaller than in air, were all subject to very intensive degradation.

Exo-emission of Electrons:—

An important means of investigating the defective properties of materials is the study of the exo-emission (thermo-emission) of electrons as a function of the temperature, which indicates the presence of various defect centres with localized electrons. Exo-emission curves obtained with a point electron counter clearly show a maximum in the temperature region between 550 and 700°K ; this occurs on all samples of materials degraded by a direct electric field, but never appears on samples of a perfect material.

Photo-Sensitivity of Titanate Materials:—

Another property of ceramic titanate materials is connected with their sensitivity to light. Immediately after firing, titanate materials have a yellow or yellowish-brown colour. As a result of daylight, however, weak but clear dark patches, having a greyish-blue to brownish-violet hue, appear on irradiated places within a few hours.

A number of basic experiments were carried out to clarify the conditions of production and suppression of these colour changes, particularly as a function of the wavelength of the light. It was found that colouring appears only as a result of the blue part of the spectrum. By irradiating with a red filter, on the other hand, this colouring rapidly vanishes, in the same way as by heating to a temperature of over 100°C. Colouring slowly dis-

appears when the sample is kept in the dark at normal temperature.

Not all the samples had this photo-sensitivity to the same extent. It was most apparent in samples fired in a medium having a lower partial pressure of oxygen, so that the connection between sensitivity to light and tendency to degradation as a result of a direct electric field was clearly shown.

Analysis of Results

As already mentioned, the initial purpose of this investigation was to attempt to verify experimentally the interpretation by Weyl and Terhune that degradation is the result of an aqueous film. The authors' experiments, however, refute this theory. It cannot be assumed that water could be kept on the surface of samples heated for several hours to a temperature of over 600°C in such an amount that degradation would not be slowed down. The orientation of cone formations, observed on a cross-section of samples of rutilite after degradation, which always have their peak at the negative electrode, are likewise not in agreement with any hypothesis assuming the influence of any kind of positive ions moving in the material as a result of the electric field. If gradual extension of degradation really occurs in the regions of the material concerned, as the results of the experiments show, then its carriers can only be particles with a negative charge. Of such particles, electrons primarily come into consideration, since it can hardly be assumed that there are other mobile particles with a negative charge in the material. Thus, the correct interpretation of degradation must be sought in the theory of semiconductors.

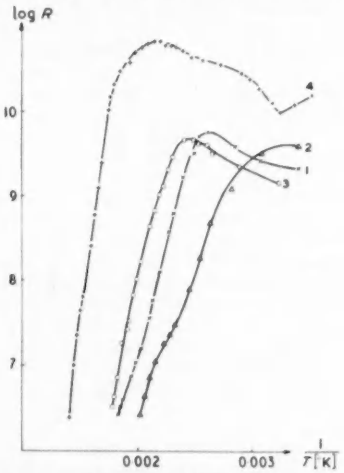


Fig. 1. Electrical resistance of a VDT condenser as a function of temperature.
(1) Condenser fired under normal conditions in an electric furnace.
(2) Degraded condenser.
(3) Condenser regenerated by firing to 800°C.
(4) Condenser fired in an oxidizing medium.

The result of studying changes in weight for degradation as a result of a voltage and after energy reduction in a hydrogen atmosphere is worthy of note. In both cases, there was a change in the appearance of the materials and, in the second case, there was a substantial change in electrical resistance, which decreased to tens of ohms. From the changes found in the weight, it follows that in this case there was a change in valency of about 10^{-2} of the total number of titanium ions. At the same time, the original structure of the rutile is untouched by the reduction. Reduction cannot, therefore, be regarded as a chemical change in the mass, but as the creation of a certain concentration of defects, in this case of holes left by oxygen ions, i.e., Schottky defects. As has already been shown by other investigators, equilibrium is reached between the number of oxygen holes and the external partial pressure of oxygen. A certain number of holes, naturally much smaller and as yet numerically undefinable, are thus produced during firing with access of air. To achieve electro-neutrality of the lattice, two titanium ions in the neighbourhood of each hole must decrease their valency from 4 to 3. A trivalent ion of titanium differs from a tetravalent ion in that one surplus, loosely-bound electron is localized in it, and is capable of passing into the conductivity band in certain circumstances. The influence of firing on the initial internal resistance of the dielectric is seen in Fig. 1.

The existence of holes and free localized electrons in titanium ions is not, of course, sufficient in itself to explain the processes connected with degradation, particularly the gradual deterioration of electrical properties and breakdown at a much lower voltage than the original.

The solution follows from studying the secondary effects, conditioned by the existence of holes in crystals. With alkaline halides the production of so-called colour centres (*F* centres), produced by an electron being captured in a hole left by a negative ion, has been studied in detail. An electron bound in these colour centres manifests itself by absorption in the visible part of the spectrum, i.e., by colouring the crystal and increasing its electric conductivity at higher temperatures.

Electrons pass into holes, for example, as a result of illumination with energy radiation, which frees the electrons from their original places. On the other hand, irradiation with long-wave light, which suffices only to expel electrons bound in colour centres, causes discoloration of the crystal. As has been shown, titanate materials behave in exactly this way. This fact leads to the opinion that the colouring and decrease in dielectric strength of titanate materials, caused by permanent direct loading, is equally explicable by the production of colour centres. The correctness of this explanation is confirmed by the result obtained from measuring the exo-emission of electrons on degraded materials.

From the results of the above experiments and considerations, the following general picture of the conditions for and course of degradation is suggested:—The firing of a titanate ceramic in a medium having insufficient partial pressure of oxygen leads to the breaking away of some oxygen ions, thus forming holes. The presence of these holes is obviously capable of affecting the electrical properties of the material and its further changes, despite the fact that their concentration is so small that they are not shown by a decrease in the mass of the sample.

A material containing oxygen holes is subject in an electric field to changes leading to the production of colour centres. The mechanism of their production as a result of an electric field is obviously not, however, quite analogous with their production by irradiation. It depends rather on the passage of the current through the material, but a more exact explanation has not yet been found, chiefly owing to the lack of experimental material.

This interpretation is therefore only a rough outline of the mechanism of degradation of titanate materials, but explains quite well the processes so far observed and forms the basis for further experimental work.

Comparative Studies of Pistons used in Hydraulic Control Systems

By V. N. Veller and A. A. Zhuravleva. (From *Teploenergetika*, No. 2, February 1958, pp. 36–43, 9 illustrations.)

In hydraulic control systems, wide use has been made of piston elements in valves, boosters, and regulators, and improved sensitivity of such systems has been achieved by means of rotating and self-centering pistons.

Comparative characteristics of these pistons have been obtained on the special test rig shown diagrammatically in Fig. 1, in which two pistons (1) and (2) are connected by a rod (6) and slide freely in the cylinders (4) and (5) fixed to the body of the equipment. Oil passes through a valve (3) into the upper space of cylinder (4) and then flows through an opening controlled by the cone (7) of piston (1). Similarly, oil passes into the lower space of cylinder (5), but with no continuous flow, other than along the piston wall. Leakage oil past the pistons of cylinders (4) and (5) is drained through pipes (8) and (9) respectively.

To impose transverse forces and tilting couples on the piston assembly, oil is fed through channels at pressures p_3, p_4, and p_5, which can be varied, as desired, to produce different magnitudes of transverse forces and tilting couples on the rod (6) and hence on the pistons. By virtue of the design of this equipment, the imposition of transverse forces on the rod does not give rise to additional insensitivity.

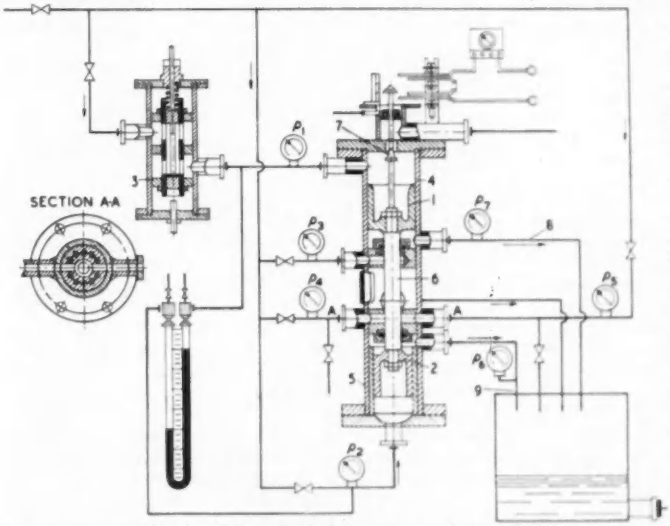


Fig. 1. **Diagrammatic layout of test rig for pistons.**

Since the pressure p_2 exists without a through-flow of oil, and pressure p_1 with a through-flow, then the value of p_2 will always be greater than that of p_1, when oil is fed from a common supply system. In order to obtain an internal balance of forces, piston (1) was constructed with a diameter of 105 mm, and piston (2) with a diameter of 90 mm. The pressure difference $p_2 - p_1$ was measured by means of a differential pressure gauge to an accuracy of 1 mm Hg.

In carrying out actual tests, only pressure p_1 was measured, as the value of pressure p_2 remained virtually constant. Hence, in the presence of a friction force T, the equilibrium of forces can be expressed as $p_2A_2 - p_1A_1 = T$ during the upward motion of the pistons, and as $p_1'A_1 - p_2A_2 = T$ during the downward motion of the pistons, where A_1 is the area of the upper piston, and A_2 the area of the lower piston.

As a result,

$$A_1(p_1' - p_1) = 2T \quad .. \quad .. \quad .. \quad (1)$$

Suppose the measured pressure differences to be $p_2 - p_1 = h$, and $p_2 - p_1' = h'$. Consequently,

$$p_1' - p_1 = h - h' \quad .. \quad .. \quad .. \quad (2)$$

and, from eq. (1),

$$A_1(h - h') = 2T \quad .. \quad .. \quad .. \quad (3)$$

The degree of insensitivity ε was taken as

$$\varepsilon = \frac{2T}{p_2A_2} = \frac{A_1(h - h')}{p_2A_2} \quad .. \quad (4)$$

The magnitude of the tilting couple on the pistons was determined from the ratio of the lever arms of the imposed couple and the reaction couple. The lever arm of the reaction couple was assumed to be equal to the distance between the centres of the piston lengths.

Investigations were carried out on three types of pistons, i.e., (1) rotating pistons, (2) special grooved pistons designed by the Central Boiler and Turbine Institute, and (3) self-centering pistons designed by the All-Union Heat-Engineering Institute.

Rotating Pistons

Two designs of rotating piston were tested, i.e., pistons with helical grooves on their cylindrical surface (Fig. 2a), and pistons with nozzles (Fig. 2b), these nozzles forming a small oil turbine and being produced by inclined holes in the piston.

Initially, the cylindrical surface of the pistons was smooth. However, with this design, it was found that enough torque to rotate the pistons could not be produced, even with increased oil pressure, because the transverse force arising as a result of pressure differences in the clearance was too large. Consequently, these rotating pistons were fitted with deep grooves, so that a turning moment was created by oil flow along these grooves, which were turned in the cylindrical surface of the pistons in the form of a two-start thread (Fig. 2a).

From the results of tests on non-rotating pistons, the degree of insensitivity ε was found to be from 12 to 14% over the whole of the stroke, i.e., friction force T did not depend on the position of the piston. Variations of transverse forces and tilting couples produced no changes in insensitivity, indicating that some other reason existed for the occurrence of friction force T, which was found to be 18·1 kg. Taking the coefficient f of semi-dry friction as 0·12, the transverse force N was therefore about 150·8 kg. As the area of the lateral projection of

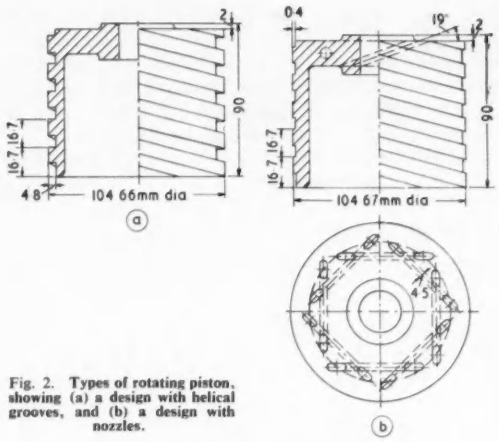


Fig. 2. Types of rotating piston, showing (a) a design with helical grooves, and (b) a design with nozzles.

the pistons was 166·5 cm², the average pressure difference between the two sides of both pistons was 0·9 kg/cm².

In comparison with these considerable transverse forces, the imposed transverse forces and tilting couples (9 to 20 kg) on both pistons could not significantly affect the friction force T. As already mentioned, rotation could be achieved only after helical grooves had been cut in the cylindrical surface of the pistons, the presence of these grooves equalizing the pressure along the cylindrical surfaces and thus reducing friction force.

The results of tests showed that, with rotation, the presence of transverse forces or tilting couples did not lead to insensitivity. However, if the pistons were stationary, the degree of insensitivity ε rose to between 1·5 and 2·5%, the corresponding friction force T being 1·85 to 3·08 kg.

Assuming that the grooves cause the resultant transverse force due to pressure differences to be completely equalized, the coefficient of friction f varies from 0·76 to 0·13, the imposed transverse force N being 24·5 kg, indicating the persistence of transverse forces due to pressure differences, even with helical grooves on the piston surface.

In the absence of imposed transverse forces, the degree of insensitivity ε of non-rotating pistons was found to be 0·07%, the friction force T being 0·08 kg. With a coefficient of friction f of 0·10, the value of the transverse force N, even in the presence of helical grooves, is therefore 0·8 kg.

The larger the transverse forces, the greater will be the initial torque required to set the piston in motion. Variation in the flow of oil through nozzles and an increase in transverse forces caused the piston to stop. According to the test results, the limiting transverse force N_L at which the piston stops can be expressed by the relation

$$N_L = 2{\cdot}3G - 5 \quad [\text{kg}] \qquad .. \qquad .. \qquad (5)$$

where G is the oil consumption [tons per hour] for rotating the piston.

From the above relation, it is found that, for a certain oil consumption, the piston is stationary, even in the absence of transverse forces. Assuming that there is, in fact, zero oil delivery through the nozzles in the absence of a transverse force, it is possible to find the additional transverse force over and above the external forces. The value of this additional force is 5 kg, which agrees well with the above evaluation.

By choosing a suitable coefficient of semi-dry friction f and knowing the value of the transverse forces, it is possible to find the minimum torque at which the piston can just start rotating.

Tests have shown that a piston with helical grooves has a considerably smaller load-carrying capacity than a piston with nozzles. In the presence of transverse forces, the friction force T becomes greater, giving rise to insensitivity, even with rotation. Consequently, in designs with helical grooves, the nominal speed of rotation should be chosen correspondingly greater than for pistons with nozzles. Experimental results indicate that the speed of rotation of the piston decreases in proportion to the increase in transverse force, while a tilting couple exercises a greater effect than a transverse force.

From a comparison of the results obtained, it follows that rotating pistons fitted with nozzles are better able to resist transverse forces and tilting couples than those fitted with deep helical grooves. However, pistons with nozzles should be fitted with shallow grooves, so as to reduce the asymmetrical pressure distribution of the oil in the clearance.

With the same test rig, a check was made of variations in oil consumption, with and without rotation of the pistons. For this purpose, the upper piston (1) in Fig. 1 was replaced by a special piston with a smooth cylindrical surface, 20 mm in width. The diametrical clearance between the walls of the piston and the cylinder was 0·32 mm, with a piston diameter of 105 mm. With the piston stationary, the consumption of oil, i.e., the leakage of oil through the clearance, was 340 kg/hr with an oil temperature of 31·6°C and an oil pressure of about 44 psig, and 554 kg/hr with an oil temperature of 39·5°C and an oil pressure of about 44·3 psig. With the piston rotating at 202 rpm, the leakage through the clearance was reduced to 205 kg/hr with an oil temperature of 30°C, and to 325 kg/hr at a rotational speed of 430 rpm and an oil temperature of 39·4°C. This reduction is explained by the fact that the rotating piston is more nearly concentrically positioned in relation to the cylinder bore.

Special Grooved Pistons

The characteristic feature of this type of piston (Fig. 3) is the provision of wide shallow grooves in its cylindrical surface, so that contact between the cylinder and the piston walls is possible only along narrow bands. In the opinion of the authors, such grooves eliminate asymmetrical pressure distributions in the clearance, but cannot produce centralizing forces.

Experiments showed that even small tilting couples

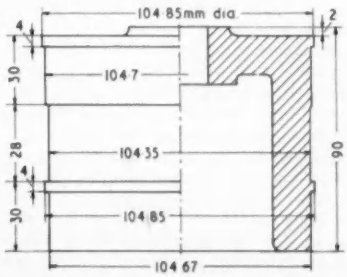


Fig. 3. Special design of piston with wide shallow grooves.

cause a considerable increase in insensitivity. This can be explained by the fact that, with tilting couples, there is a sharp-edged contact between the pistons and the cylinder walls, as a result of which semi-dry friction arises. Transverse forces have relatively little effect until they cause oil to be squeezed out of the region of contact of the bands with the cylinder bores, but, as soon as this occurs, semi-dry friction arises and insensitivity increases sharply.

With a tilting couple, the average degree of insensitivity is a linear function of the couple, and, plotted graphically, is a straight line which passes through the origin of the co-ordinates, thereby confirming the assumption of complete symmetry of oil-pressure distribution in the clearance. The coefficient of friction f is about 0·23, this high value being due, as already mentioned, to sharp-edged contact between the piston and cylinder wall. In the absence of a transverse force or a tilting couple, the degree of insensitivity ε of these pistons was found to be 0·07%.

Leakage of oil through the clearance varied little with changes in transverse force, confirming that the oil film between the rubbing surfaces was very thin. The absolute leakage rate in the tests carried out with these pistons was about 160 kg/hr with an oil temperature of 44°C. As in the case of the rotating pistons previously described, an increase in oil temperature caused a higher leakage rate.

Self-Centering Pistons

The investigations established that, in order to produce piston mechanisms of high sensitivity, it is essential to equalize the pressures on the walls of the piston and also to balance the transverse force and the tilting couple. In addition, the oil film between the rubbing surfaces must in all cases be maintained, and, although this can be achieved quite reliably by the use of rotating pistons, especially those incorporating nozzles, a comparatively large quantity of oil is required for rotation.

In the design of self-centering piston shown in Fig. 4, an even number of recesses is machined in the piston wall, each recess being connected by a small-diameter hole with the interior of the piston. An annular drainage channel connects the holes with the overflow space and is located on the delivery side of the piston surface between the centralizing recesses and the edge of the piston.

On displacing the piston to one side of the cylinder bore, the clearance δ varies. Thus, with a smaller clearance δ_1, resistance to the flow of oil increases, and the pressure p_1 in the adjoining space also increases. On the opposite side, clearance δ_2 will be a maximum and the resistance to oil flow a minimum, so that pressure p_2 drops. The pressure difference $p_1 - p_2$ acting on the area of the recesses creates a force which tends to push the piston towards the centre.

The drainage channel serves to increase this centralizing force by preventing oil from passing through the clearance into the centralizing recesses. Without this channel, oil supply to the centralizing recesses would take place through the annular clearance ; with the larger clearance δ_2, the supply of oil would also be larger, thereby raising the pressure p_2 in the appropriate recess. Similarly, with the smaller clearance δ_1, the oil supply would decrease, leading to a drop in pressure p_1. As a result, the pressure difference $p_1 - p_2$ would decrease, and the self-centering tendency of the piston would become less effective.

Tests were carried out on self-centering pistons of this type, with holes of 1-mm diameter in the recess and a clearance δ of 0·14 mm in the upper piston and 0·20 mm in the lower piston. In addition, another series of tests was carried out on pistons with holes of 2-mm diameter and a clearance δ of 0·32 mm in the upper piston and 0·30 mm in the lower piston.

The degree of insensitivity ε was found to be small in both cases, not exceeding 0·06% under a transverse force and under a tilting couple. Tests on a piston with the centralizing ports blocked showed, as was to be expected, a sharp increase in insensitivity, but, even so, its value did not exceed that of an ordinary smooth-walled piston.

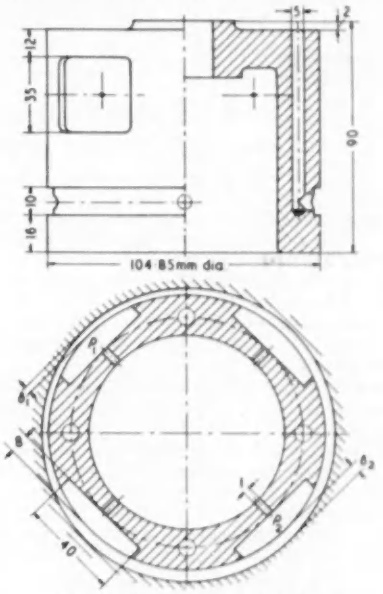


Fig. 4. One design of self-centering piston.

From the results obtained, it has been established that self-centering pistons ensure practically a zero degree of insensitivity both under transverse forces and tilting couples. Furthermore, an increase in the diameter of the holes supplying oil to the centralizing recesses, with a corresponding increase in the clearance δ, leads to increased sensitivity. This is due to the fact that the minimum clearance for the corresponding transverse force or tilting couple increases, and hence any effects of roughness of the piston surface and cylinder bore are diminished.

The total oil leakage rate in self-centering pistons of this type was found to be about 720 kg/hr for pistons with a hole diameter of 1 mm and respective clearances δ of 0·14 and 0·20 mm, and about 2430 kg/hr for pistons with a hole diameter of 2 mm and clearances δ of 0·30 and 0·32 mm. With pistons of the rotating type, this would correspond to an equivalent leakage rate of more than 12,500 kg/hr.

A modification of this design of self-centering piston has been developed by the Central Boiler and Turbine Institute, in which the oil supply to the centralizing recesses takes place through flats on the delivery side of the piston. In this method, the supply channel cannot be blocked. Nevertheless, any of the coarser particles normally removed by the sharp edges of the piston may drop onto the flats and, although this would not block the oil

supply to the recesses, it could lead to an even more dangerous condition, i.e., jamming of the piston. To prevent this danger, a suitable filter should be installed in the oil supply. Furthermore, the supply of pressure oil through the flats does not permit the holes to be filled, so that the centralizing capacity of the recesses is lowered.

An important feature of self-centering pistons is that the centralizing force develops before motion of the piston is initiated, as distinct from rotating pistons, in which the centralizing force acts only after rotation has commenced. Moreover, in rotating pistons, there is dry or semi-dry friction, and it is therefore essential that the rubbing elements should be of appropriate materials possessing optimum anti-friction properties. In the case of self-centering pistons, however, the materials used in the construction of the contacting elements are apparently not important, as has been demonstrated by experience with a self-centering valve spool of untreated steel which has been operating satisfactorily in a cylinder of the same material for more than two years. This valve operates with water and its degree of insensitivity is still virtually zero.

GERMANY

Investigation into the Shut-Down Behaviour of Hydraulic Steam-Turbine Governors

By W. Petow. (From *Siemens Zeitschrift*, Vol. 32, No. 6, June 1958, pp. 393–400, 10 illustrations.)

The great demand for electric power in recent years has led to the construction of turbo-generator sets with increased power ratings, obtained by a maximum utilization of materials, particularly in the generators. As a result, acceleration times have been greatly reduced, so that more stringent requirements are being stipulated for turbine-governing systems, particularly as regards speed of response and sensitivity.

Satisfactory governing characteristics and a good shut-down behaviour are nearly always obtainable with turbine sets requiring 12 sec to run up to speed, but nowadays condensing turbines developing over 110 MW require 11 sec, while topping-turbines require from 3·2 to 3·5 sec, so that these systems necessitate closer study.

Mathematical analyses are valid only within the limits of their simplifying assumptions, as the governor is a fairly complex unit and there are non-linearities in the entire system ; consequently, the solutions obtained are only approximate and do not fully agree with experimental values.

Measurements carried out in the power station itself give reliable results, but obviously it is rarely possible, for practical reasons, to carry out a full programme of governor testing. This is also true at the manufacturer's works, where full-scale tests would be difficult, owing to the large size of the turbines involved, the great quantities of steam required, and the necessary variations in test parameters. For these reasons, it is convenient to carry out tests with the aid of a model system of the type described in this article.

Testing of Governors in a Model System

Scale models frequently have the disadvantage of producing results which differ from those of the full-size installation. It was therefore decided to use a model only for the controlled system and to connect it to the actual governor under test. The model chosen for this work is a small 10-kW turbo-generator with continuously adjustable characteristics, and its parameters can be varied so as to obtain representative numerical values for a wide variety of large turbine sets. The required values of time for running up to speed can be obtained by adjusting the power output and the live-steam pressure, giving a continuous range of values from 14·5 sec at 3 kW, through 6 sec at 6 kW, to 3·3 sec at 12 kW.

The model system, set up on a test-bed, consists of various units, i.e., (1) a radial turbine, (2) a 115-V d.c. compound-wound generator rated at 10 kW, with an output kept fairly constant by means of an auxiliary series-connected winding, (3) two adjustable resistors for the load, (4) equipment for switching off full load and partial loads, and (5) provision for installing governors of various types. The installation also includes oil pumps, an oil tank, and filter arrangements. In addition, to maintain specified values of oil temperature, two heat exchangers, a water pump, and a water tank are fitted.

When disturbances in the grid and supply of steam produce temperature and pressure fluctuations, with consequent variations in running speed, corresponding variations are produced in power output and frequency. The instantaneous values are compared in a feedback discriminator with preset or programme-controlled reference values, and the deviation, i.e., the error signal, is amplified and fed to the governor system.

A schematic drawing of a governor is shown in Fig. 1, the governor being designed to control turbine speed when the set is operating independently. A pump, driven from the turbine shaft, generates an oil pressure which is proportional to the square of the running speed. This oil pressure acts on a bellows, displacing a lever connected to the sleeve of a pilot control valve. The piston in this unit is displaced by oil pressure, acting against the tension of a spring, until the oil can escape through the control ports. The amount of oil escaping regulates the secondary oil pressure, which is transmitted to the relay valve through a damper, and acts on the lower surface of the relay-valve piston against a spring, whose compression is adjusted by a cam-and-follower mechanism. The relay-valve piston admits pressure-oil to the servo-piston, which actuates the steam-regulating valve. The desired speed is obtained by adjusting the preload of the control spring electrically or by means of a handwheel. A manometer/tachometer unit, connected to the oil pump mounted on the turbine shaft, measures the primary oil pressure and indicates turbine speed.

Considerable attention has been given to instrumentation. All measured values are recorded on a single strip by means of a six-channel oscillograph, a 50-cps trace being used for time markings. Instantaneous turbine speed is indicated by a tachometer-generator of the permanent-magnet type, its output voltage, which is directly proportional to speed, being passed through a multi-phase rectifier and a smoothing circuit with a very low time-constant. The rectified signal is then partially

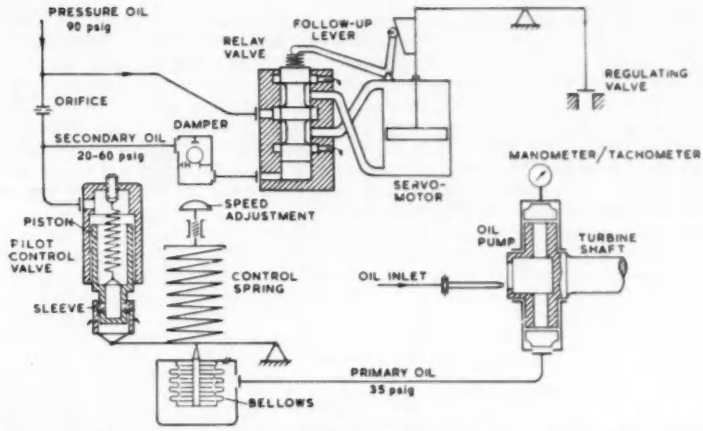


Fig. 1. Schematic arrangement of a hydraulic steam-turbine governor system.

compensated by a constant d.c. voltage. The difference voltage, fed to an amplifier connected to the oscillograph, gives a direct indication of speed variation.

Variations of primary and secondary oil pressures and of the oil pressures above and below the servo-piston are indicated by diaphragm-type pressure pick-ups, with the oil pressure acting on one side, while a strain-gauge is bonded to the other side. A second strain-gauge is used for temperature compensation, and its signal is fed to a bridge connected to the oscillograph.

Valve displacements up to about 5 in. are indicated by a rheostat fitted to the rod of the servo-piston, the brush-gear being insensitive to vibration and the output passed through a resistance connected to one of the channels of the oscillograph.

Measurements are synchronized by current pulses occurring once per second, triggered by a precision chronometer. Small movements of about 0·2 to 0·3 in. of the sleeve of the pilot control valve and of the relay piston are indicated by rotary potentiometers, giving accurate oscillographic recordings to 0·004 in. A voltmeter and an ammeter are used to read the output of the generator, but, in order to determine the exact moment of switching, current is also registered on the oscillograph. The various oil pressures of the governor and the steam pressures of the model turbine are measured with precision gauges. Various other instruments are used to supervise general operating conditions.

Tests were made on a governor operating with proportional control, the model system being adjusted to run up to speed in 3·8 sec, which is a representative value for modern topping-turbines. In each test, the highest possible load that could be obtained from the extreme position of the servo-piston was switched off. The influence of entrapped steam was virtually eliminated by keeping the volume of steam between the regulating valve and the nozzle to an extremely small value. Switching from full load was carried out with the turbine operating at a speed of 3000 rpm. The regulating valve was fully open, oil pressure was set to about 90 psig, and a proportionality band of 3% was used.

The shut-down process was initiated by tripping the switch. The generator current dropped to zero and simultaneously running speed increased to a maximum value of 3230 rpm, this peak speed being reached in 0·414 sec, after which the regulating valve closed fully. The total time of 0·414 sec was made up of 0·045 sec lag of the primary signal relative to the running speed, 0·079 sec delay in the action of the control-oil pressure, and 0·290 sec for the valves to reach their zero-load position. This low value of 0·290 sec for the actual operating time kept the overshoot to a small value. Because of the high valve-closing speed, the oil pressure dropped from 90 to about 65 psig for a brief period.

The above results show that this particular governor can limit overshoot to less than 8% above the preset

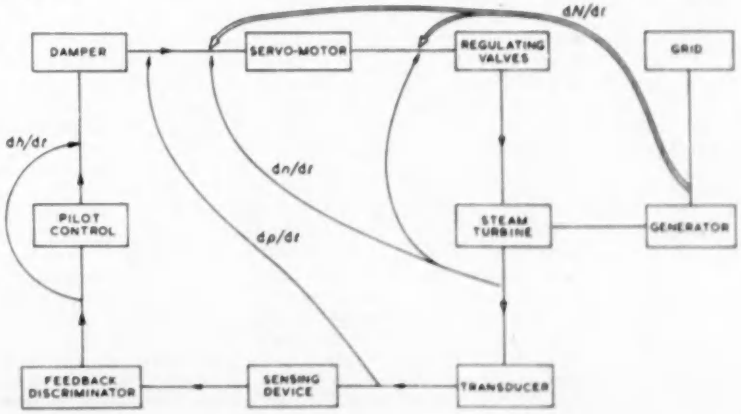


Fig. 2. Block diagram illustrating various possibilities of derivative control.

value, in the case of a turbine set designed to run up to speed in 3·8 sec.

Improvement in Control by Incorporating Derivative Action

For topping turbines which run up to speed very quickly, the response of a governor with proportional control may not be sufficiently rapid, particularly if the proportionality band is fairly large, as so much time elapses until valve closure occurs that the running speed frequently rises to the emergency shut-down level. To prevent rises in speed up to this level the governor can, however, be designed to make use of the derivative dq/dt of the controlled quantity q with respect to time t. By means of the time-derivative of the error signal, the positioning variable can act with a phase lead relative to the error, when sudden load removal occurs. Steep rises in speed accentuate the derivative action.

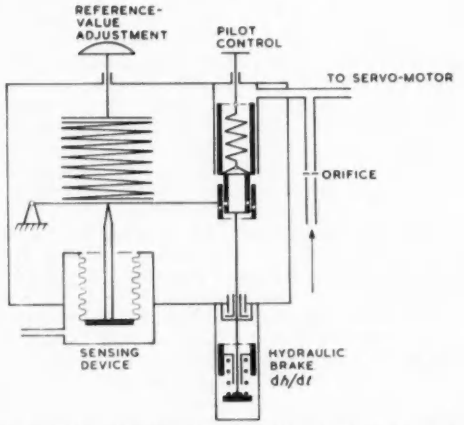


Fig. 3. Circuit using derivative dh/dt of the stroke of the pilot control element.

There are many ways in which such derivative action can be used, but limits are set by design factors. Tests have been carried out to determine which components of the various types of governors investigated give rise to delays in response and which elements are important as regards overspeed. These tests have indicated the following possibilities for the inclusion of derivative or pre-sensing action (Fig. 2) :—

(1) Time lags due to the pilot control can be eliminated by adding a device which responds to the derivative dh/dt of the stroke h of the pilot-control element.

(2) Sluggish response of the sensing elements, coupled with time lags in the pilot control, can be overcome by taking the derivative dp/dt of the control-oil pressure p and allowing it to act in the control circuit ahead of the servo-motor.

(3) To reduce time lags in the transducer, the derivative dn/dt of speed n can be introduced either ahead of or after the servo-motor.

(4) When very stringent requirements are set for the governing of a turbo-generator system, it is convenient to feed back the derivative of the disturbance occurring within the control system itself, instead of waiting until the disturbance has acted on the controlled quantity. With this feedback, the lost-motion times of the governor are completely eliminated. For instance, the derivative dN/dt of the power output N can be taken and fed into the control circuit, ahead of or after the servo-motor.

Tests were conducted on a derivative circuit designed to respond to dh/dt and using hydraulic braking acting only in one direction (Fig. 3). The braking piston prevents excessively rapid upward movements of the pilot piston, so that its control sleeve becomes more effective. As a result, the secondary oil pressure falls off more rapidly, and the regulating valves close ahead of the time otherwise required.

In a first test, using the model system, the speed variation without this derivative action was recorded. With a time of 3·6 sec to run up to speed and a proportionality band of 6·1%, the system ran up to its emergency-trip speed when the load was thrown off. The second test utilized the same parameters but incorporated the derivative control. In this test, when the load was removed, the speed rose from 3000 to 3210 rpm, i.e., 10 rpm below the no-load speed of 3220 rpm. Thus, the improvement in behaviour was evident, in spite of the increased proportionality band (6·1% instead of the 3·0% used in the switching tests previously described). Measurements in several power stations in which this derivative circuit has been added confirm the results obtained on the model system, and show that proportional and derivative control fulfil the requirements for turbo-generator units which run up to speed rapidly.

Advantages of the Model System

Tests on full-size governors coupled to a model system have the advantage of allowing a wide range of parameters to be explored rapidly, without extensive calculations, and more simply than in tests on full-scale turbo-alternator sets. Time lags or permanent deviations of error signals can be identified and corrected at an early stage, so as to obtain optimum conditions, and the results are sufficiently accurate and agree with those subsequently measured in the power stations themselves.

Particular effects, such as those due to inertia, oil flow, and friction, can be investigated in detail. The system has been further developed to investigate control problems occurring in the parallel operation of turbo-generator units, and, in addition, can be used as a process-control simulator for the instruction and training of personnel.

High-Strength Non-Magnetic Alloys

(Concluded from page 401)

Type 310 stainless steel (24–26% Cr, 19–22% Ni) is far more magnetically stable than type 304, its permeability being 1·003, even after processing. Like type 304, type 310 stainless steel can only be strengthened by cold-working, its tensile strength being increased from 75,000 psi in the annealed state to 175,000 psi after 50% cold-working.

An age-hardening stainless steel containing 15% Mn, 15% Cr, and 2% V is now available in one grade for non-magnetic applications. The recommended heat treatment consists of a solution treatment at 2100°F for 15 min, followed by a water-quench and ageing at 1300°F for 8 hr. After treatment, the alloy has a tensile strength of 195,000 psi and a permeability of less than 1·01.

Cold-work after heat treatment produces a phase change which has an adverse effect on magnetic characteristics. Thus, after 40% cold-working, permeability increases to 1·2, so that, apart from the heat treatment mentioned above, no further processing is recommended.

Q

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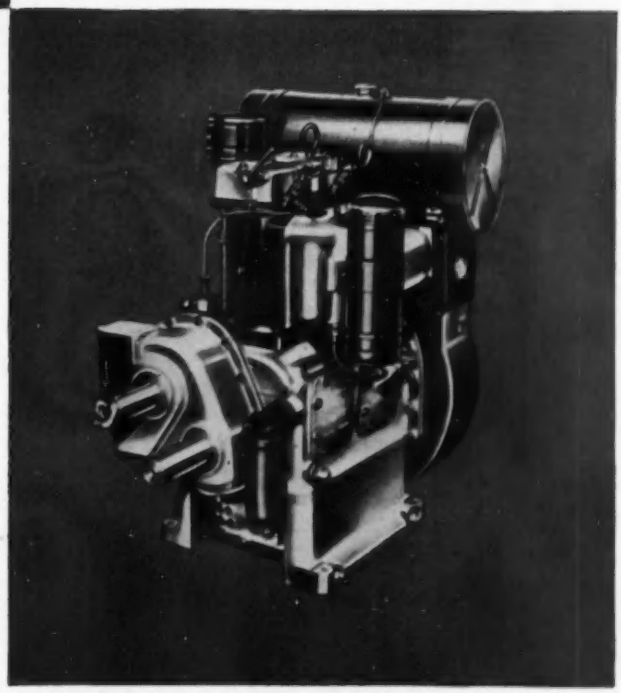

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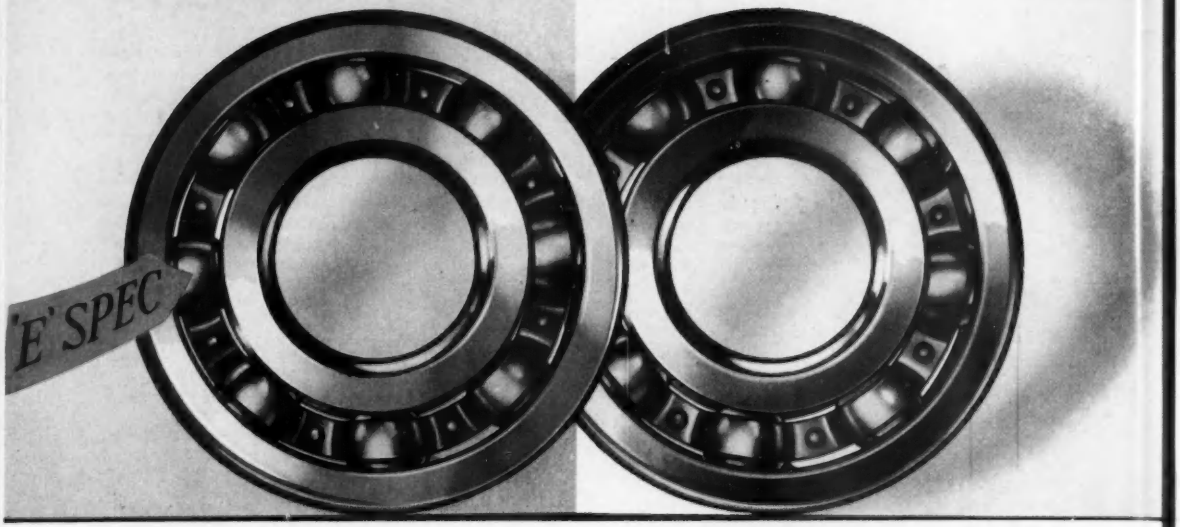

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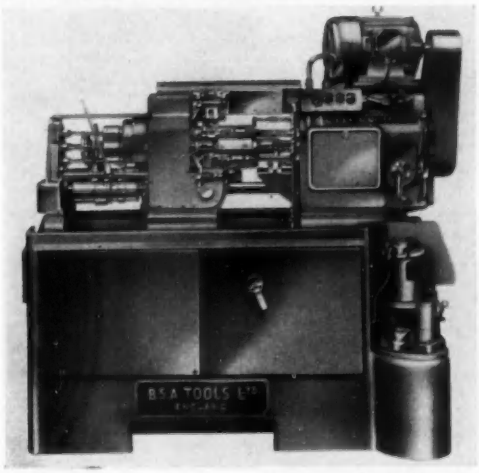
Multi-Spindle Bar Automatics

The latest addition to the range of B.S.A. Acme-Gridley multi-spindle bar automatics produced by B.S.A. Tools Ltd., of Kitts Green, Birmingham, is their $\frac{7}{16}$-in. six-spindle machine. Fast, accurate, and versatile, the new machine, which is intended for the production of small-type components, is fitted with independently operated tool slides, thereby affording extremely wide adaptability for standard and special attachments. Although special attention has been paid to convenience of setting-up and operation, the basic principles of the larger B.S.A. Acme-Gridley multi-spindle range have been retained. Change-over can be achieved with the minimum of delay, because of easy accessibility to the tooling area, cams, and change-gears. The machine is only $5\frac{1}{2}$ ft long, but its height allows the operator to work erect and in a comfortable position.



Permanent accuracy and alignment of spindles and tool slide is assured. The main tool slide, which is mounted directly on the stem, is kept in perfect alignment with the spindles by having the hardened stem let into the spindle carrier and ground at the same setting. The stock-reel is independently power-indexed through a separate shaft and gear, eliminating torsional strain, any tendency to whipping action, and excessive wear in the spindle carrier. In addition, the entire stock-feeding mechanism is rigidly supported at both ends. A stock depletion feed knock-out is fitted. To prevent chuck release while the tools are working, a housing, which encloses the spindle drive gears, acts as a guard and holds the chucking spools in position. The chucking and feeding slides are mounted on long bearings, preventing tipping and binding, whilst the chucking shoes have wide bearing surfaces on the chucking spools.

A finger holder mechanism permits rapid feed through the collet and allows full range of spindle speeds to be utilized without affecting the chucking mechanism. For collet closing, a cam mechanism operates the fingers, but, for collet opening, centrifugal force, instead of springs, is used to spread the fingers. The bar-stock ends are quickly removed by a manually operated chucking mechanism. The chucking and feeding cams are easily accessible on a drum under the chucking slide. A swing stock-stop is incorporated in this machine, and is operated directly from the main drum shaft. After the stock is fed and the collet closed, its " rest " position is below the surface of the two side slides, permitting the use of the stock-feeding mechanism for tooling and allowing easy access to tools.

The spindle carrier begins to index from a standstill by using a modified Geneva mechanism. This rapidly accelerates, then decelerates, bringing the movement to a shockless dead stop before the locking pin is engaged. The headstock encloses the entire indexing mechanism. The robust lower cross slides and top slides, which operate independently in hardened steel ways, enable heavy cuts at high speeds to be used without fear of vibration or chatter. For tool setting the cross slide can be hand-operated.

By removing a cover at the motor end of the machine access can be gained to the feed and speed change-gears, which give a wide range of speeds and a comprehensive selection of feeds. The main tool slide can easily be arranged to take a combination of tools, such as turning and high-speed drilling in one position. Close control of depths of holes when drilling or reaming, and length when turning is arranged by a positive stop. The drum for the main tool is readily accessible from both sides of the machine, and for maximum roller contact the cams have wide faces. The drum is completely free from chips and coolant. The tool slide is mounted on a bracket below the slide, leaving the two die slides in the third and fourth positions for independently operated threading attachments or for accelerated drilling and reaming attachments. To simplify setting, where components of differing lengths are used, a variable fine end adjustment to the tool slide in relation to the collets is incorporated.

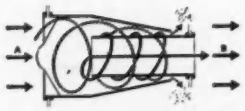
The machine employs an efficient braking mechanism, combined with the use of large disc and roller clutches in the gearbox. Three push-buttons are provided on each side of the machine, giving start, stop, and inching, with an additional button for the coolant pump and feed re-set. A compartment in the machine base houses the electrical equipment, which is accessible through doors, the opening handle of which is also an isolation switch.

New Central Heat-Treatment Plant

In the past, the Darley Dale and Tinsley works of The Firth-Derihon Stampings Limited were responsible for the heat treatment of their own production. Now, however, with the commissioning of their new central heat-treatment plant at the Darley Dale works, all heat-treatment requirements of the company are concentrated in one plant.

The new plant, which incorporates many advanced ideas, was designed jointly with Gibbons Bros. Ltd., Honeywell Brown Ltd., Hartons Ltd., and members of the Brown-Firth Research Laboratory, and basically comprises three Gibbons dual-system heat-treatment furnaces, two Gibbons tempering furnaces, a Gibbons oil-quench machine, a Gibbons-Van Marle turntable charging machine, with loading tables and special-type cooling tables, an instrument control room, and a centralized waste-gas discharge system.

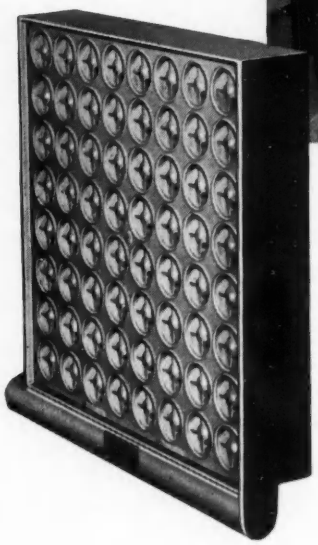
All furnaces, which are fired by town gas, are 11 ft in length, $6\frac{1}{2}$ ft in width, and $3\frac{1}{2}$ ft in height to the spring line of arch in doorways. Furnace loads up to 5 tons are handled. The dual-system furnaces have normal operating-temperature ranges between 200 and 750°C with forced recirculation, and between 750 and 1250°C without forced recirculation. The normal operating temperature of the tempering furnaces is from 200 to 750°C with forced recirculation.

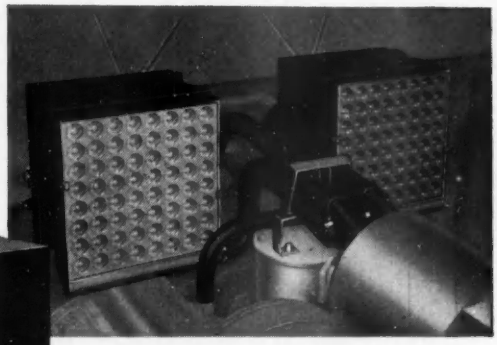


Rotonamic

air filters for DIESELS

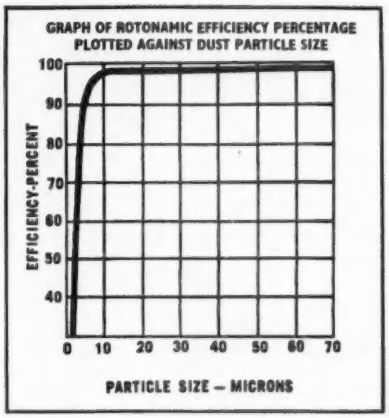
Static helical blades in the ROTONAMIC air filter give a whirling motion to the air as it enters at A. Still keeping to a helical path, the air is then induced to reverse direction, centrifuging the solids out of suspension before 90% of it is fed to the engine B. The other 10% is aspirated away with the removed solids through the tube at the base of the panel.





HIGH EFFICIENCY FILTRATION for DIESELS

Diesel life and efficiency goes up—when ROTONAMIC takes the abrasives out of the aspirated air. Road and railway transport system operators report: "periods between overhauls extended by hundreds of working hours. Greatly extended engine life".



NO MAINTENANCE and extremely high efficiency are the most important money-saving factors of ROTONAMIC air filters for diesels. Aspiration of dust particles can be provided by a simple extractor operated from the engine exhaust system. ROTONAMIC filters are made in England by INTERMIT LTD. Please write for leaflet FRC9.

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Furnace temperatures are electronically controlled by a fully automatic electro-pneumatic system, the Honeywell-Brown control instruments being housed in a centrally positioned air-conditioned instrument control room, a section of which is shown in Fig. 1. The tempering furnaces are two-zone controlled, and the dual-system furnaces single-zone controlled. Temperature distribution throughout the furnaces is held to extremely fine limits and is indicated and recorded at any six points in each furnace. All furnaces are fully instrumented and controlled to safeguard against failure for any reason. Compressed-air supply for operation of the pneumatic control equipment is obtained from duplex air compressors and receiver units mounted on top of the instrument control room, from which actuation of the air-compressor units is automatically controlled. Kent gas-flow recorders are used to record gas-flow rates and the total gas consumption of each furnace. All waste gases from the furnaces are collected through a centralized overhead waste gas main and then discharged into the atmosphere via a high-capacity waste-gas exhaust fan and chimney stack.

The oil-quench machine is of advanced design, being of the fully-enclosed type with automatic door operation. Automatic lowering and lifting of the load, with variable-controlled oscillation of load during the quench period, is also incorporated, ensuring optimum oil-flow conditions during the quenching cycle. For cooling the oil in the quench machine, the oil is drawn from the top of the tank, passed through a water-cooled oil cooler, and returned to the tank via distribution ducts in the tank base. This oil cooler is capable of dealing with 27,000 gallons of oil per hour, using 12,000 gallons of water per hour. Oil temperature is shown by an indicator on the discharge pipes from the oil tank.

Fig. 1.

The charging machine used in conjunction with the loading tables, furnaces, and oil-quench machine is an all-electric, 4-arm turntable design arranged for 5-ton loads. Four motors are used for hoisting, lowering, charging and discharging, and traversing and rotation. Power is supplied to the charging machine via a specially designed motorized cable-drum unit, mounted on the charging machine, the feed cable being laid down in a small duct below floor level. The general layout of the heat-treatment plant is shown in Fig. 2, in which the centrally located charging machine can be seen withdrawing a batch of turbine discs from the oil-quench machine.

The plant has been designed to handle large and small batch production efficiently and to eliminate manual handling, as it has to deal with a wide range of forgings, varying in weight from a few ounces up to about 800 lb. All incoming materials are received in the reception bay in stillaged form, diesel-engine forklift trucks and electric battery-operated stillage trucks being used for the

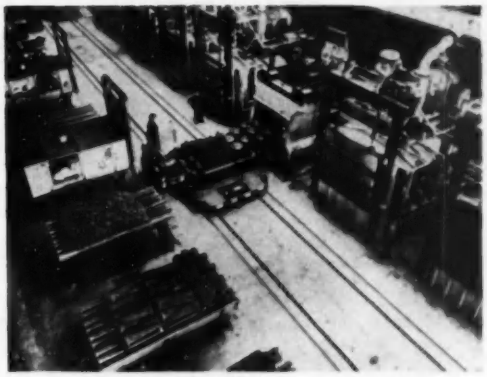

Fig. 2.

movement of all stillaged loads into the storage area, between the storage area and the loading tables, after treatment, and for the movement of stillaged loads to the adjacent inspection department.

In the main heat-treatment bay, electric overhead cranes are used for assembling the heavier forgings on the loading tables, etc. Depending on the weight and section of the forgings to be treated, these are loaded into special heat-resisting furnace trays or onto heat-resisting bearer-bars. After the load has been assembled on the loading table, it operates as a unit load throughout all subsequent operations in the heat-treatment department.

Small Aerosol-Type Fire Extinguishers

Stated to be the first of its kind in the U.K. or in Europe, the new " Gwish " aerosol-type fire extinguisher announced by Deb Chemical Proprietaries Ltd., of Belper, Derbyshire, makes it possible to locate an efficient fire-fighting appliance beside work-benches, machines, desks, etc., ready to deal instantly with minor outbreaks of fire before they develop into major conflagrations.

Marketed at less than one-third the cost of normal types of fire extinguishers, the new appliance contains 12 fluid ounces of liquid, which is released as a powerful jet spray on depressing the discharge nozzle with one finger. Removal of the finger from the nozzle completely cuts off the jet, which douses flames instantly and carries for 6 ft, with a coverage of 3-ft diameter. The extinguishing fluid used is a non-conductor of electricity and is stated to be safe and effective on all fires, irrespective of their cause. A suitable fixing bracket is supplied with each extinguisher.

Technique for the Rapid Drying of Metal Articles

A new technique for the rapid drying of metal articles has been introduced by Imperial Chemical Industries Ltd., of London, S.W.1. Metal parts are treated in trichloroethylene, to which has been added a special new additive, " Trisec ", which ensures freedom from staining, even of bright-plated and polished parts.

It is well known that wet metal articles can readily be dried by immersing them in the vapour of a boiling chlorinated solvent, such as trichloroethylene. The moisture film will dry off, because, although the boiling point of trichloroethylene (87°C) is below that of water, a mixture of solvent and water boils at an even lower temperature (73°C). Vapour-degreasing plants can therefore be used for drying small metal articles, even though the evaporation of large drops of water from the surface leaves stains. Owing to the risk of staining, however,

* This makes sense
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Made by James Neill & Co (Sheffield) Ltd., and obtainable from all tool distributors.

UT 13

Ask the machine shop to check this

such a method is not suitable for bright-plated or other polished surfaces. With the new I.C.I. technique, the idea of using trichloroethylene has been retained, but the treatment is in liquor instead of vapour and, to prevent stains forming on the articles, " Trisec " has been specially developed to be effective at moderate temperatures, so that advantage can be taken of the low heating requirements of trichloroethylene. The effect of the additive is to displace the water film on the metal surface by trichloroethylene, which readily evaporates.

The treatment is most effectively carried out in simple equipment similar to a standard degreasing plant, but incorporating a water separator and extra free-board above vapour level, and fitted for rim ventilation. One compartment, containing the " Trisec ", is used for the drying operation and the other for the subsequent rinsing of the dried parts in pure boiling trichloroethylene. This ensures that the articles are not only perfectly dry, but also quite free from grease contamination. The whole process is normally completed in about one minute.

Special Duplex Screwing Machine for Railway Coupling Screws

Specially developed for British Railways for screwing both ends of railway coupling screws simultaneously, a new duplex screwing machine announced by Joshua Heap & Co. Ltd., of Ashton-under-Lyne, is fitted with two independent headstocks, with " Tangential " dieheads, one equipped for right-hand threads and the other for left-hand threads. Each headstock is individually motor-driven and is fed under leadscrew control from its own spindle, as well as being provided with a rack-and-pinion feed.

With the " Tangential " dieheads used, the dieholders are mounted on trunnions and are enclosed by a solid cam ring which absorbs all cutting strains, so that very coarse threads can be screwed at one pass, producing perfectly parallel threads with an adequate surface finish. The coupling screws are rigidly held in a stationary vice, and the threading operation is initiated by engaging both leadscrews. At the end of the cut, both the leadscrew and the diehead are tripped automatically, and the headstocks are returned to their original position by the rack and pinion.

Catenary High-Temperature Kiln

A new high-temperature kiln has recently been introduced by the Allied Engineering Division of Ferro Enamels Limited, of Wombourn, Wolverhampton, for applications demanding wide firing-curve flexibility. The kiln, which is eminently suitable for refractories production development, filling the gap between the laboratory test kiln and production furnace kiln, is also suitable for production of special high-temperature ceramics.

The equipment incorporates a catenary arch forming the roof and side walls of the firing chamber, this method of construction having the advantage, among others, of allowing the structure to " breathe " evenly when subjected to fast heating and cooling cycles, as distinct from the more commonly used arch of constant radius, which relies on the support of external steel members.

The method of firing is down-draft through a low wide setting. A simple burner fires over the charge, flame propagation developing in the apex of the catenary. In this way, any flame impingement is confined to the wicket rather than the charge. The catenary facilitates distribution of the products of combustion through the charge to the floor of the kiln, where they are exhausted through a series of adjustable slots, so that close temperature uniformity is obtainable with varying charges. The spent products of combustion pass to a suitably dampered stack though a 3-pass silicon carbide recuperator supplied with the kiln; this provides hot combustion air to the medium-pressure water-cooled burner.

The kiln will take a charge of up to 200 standard firebricks or equivalent and will fire a charge of 160 bricks to 1760°C in 12 hr, followed by a 4-hour soak at 1720°C. At this temperature the exhaust flue temperature is only 670°C. The charge area is easily accessible for loading and unloading, and a brick setting may be stacked in a matter of 10 min. The kiln is supplied complete with automatic limiting or programme control, and oil pumping equipment.

Self-Opening Diehead with External Tripping Mechanism

The new Coventry ¼-in. style " XT " diehead announced by Alfred Herbert Ltd., of Coventry, has been specially designed for use on single-spindle automatics and, in addition to the normal features of the well-known Coventry diehead, is also equipped with an external tripping mechanism. This mechanism eliminates the possibility of the diehead opening as a result of the centrifugal force produced by very rapid indexing of the turret on high-speed machines.

A particular advantage of the diehead is its ability to cut short threads, as it can be set to trip almost immediately after the dies commence cutting. The diehead is fitted with a spring-cushioned shank which provides a lateral movement in both directions, so as to compensate for the slight difference which may exist between the pitch of the thread and the forward motion provided by the feed cam. This cushioned action ensures a good start to the thread and also, in conjunction with substantial sliding dogs, an easy sliding movement, guaranteeing a long die life. Spring pressure can be varied.

The new diehead will cut threads from 12 BA to ¼ in. Whitworth with appropriate dies and, as the shank is hollow, screws of any length can be cut. In addition, as it uses the same dies as those fitted to all ¼-in. size Coventry dieheads, the standard die-grinding fixture and height gauge can be used for regrinding.

If you have a pipe problem

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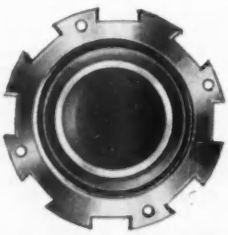
Fleximet for instance—the all-stainless steel flexible pipe that carries a very wide range of fluids or gases equally well at the extremes of high and low temperature. DUNLOP are specialists also in reinforced high and low pressure flexible pipes embodying P.T.F.E.* and rubber-like materials. *Dunlop technicians are available to advise on all problems concerning the installation and use of flexible pipes. Details from H. S. Perrey, Dunlop Rubber Co. Ltd., St. Georges Road, Coventry, Telephone 64171.*



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MAKE PIPES BETTER TO LAST LONGER

BH/904

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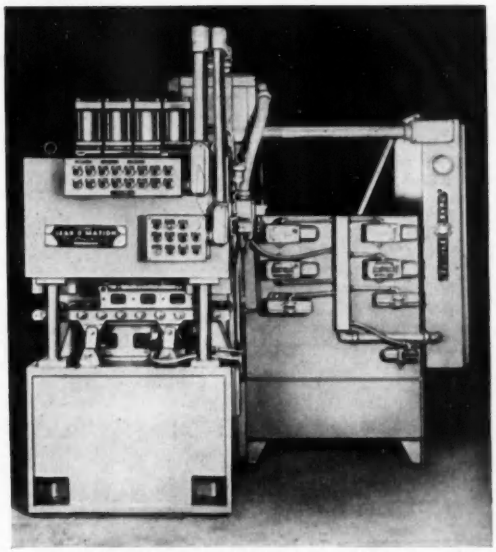
New Materials, Processes, and Equipment

MACHINE FOR PRESS-FITTING VALVE-GUIDE BUSHINGS INTO CYLINDER-HEADS

A new hydraulically operated, electrically controlled machine, recently developed by the Gear-O-Mation Division of the Michigan Tool Company, of Detroit, Michigan, is designed to press simultaneously with a predetermined force all valve-guide bushings into any one of a range of five different diesel-engine cylinder-heads. These heads are intended for two- three-, and four-cylinder engines of two types, i.e., Vee and in-line, with the three- and four-cylinder models having either two or four valves on each cylinder. The machine handles the valve-guide bushing insertion for the entire series, and also provides a visible and audible indication (signal light and bell) of any improperly positioned or loose-fitting bushings.



Versatility of the machine is obtained by means of an interlocked electrical and hydraulic circuit individually controlling four rams, in combination with easily changed ram guides. Normally, each ram press-fits two bushings for each engine cylinder, " alternate " ram guides being used when it is desired to press-fit four bushings per cylinder. The operation can also be variably controlled for either simultaneous or progressive pressing. This particular machine is semi-automatic, the bushings being preliminarily finger-positioned and the cylinder-head manually rolled into and manually rolled from the machine, but the basic design can be easily modified for fully automatic production.

In operation, the cylinder-heads, with the bushings held in place by a pilot plate, are manually fed to hydraulically operated end-stop positioners, each of which is adjustable to provide for the different cylinder-heads. The work cycle is entirely automatic. The table and work lower to the press position where, if the work is positively positioned, it makes contact with a limit-switch controlling the ram action, each ram being powered from a 3½-in. stroke, 2-in. diameter hydraulic cylinder. Only those rams which have been pre-designated by a selector switch lower to press-fit the valve-guide bushings of the particular cylinder head being run. While it is possible to operate all rams simultaneously, the machine is usually set to allow the rams to move down in sequence, the advantage being a fairly large saving in maximum power requirements, with a negligible time loss. As the rams return to their dwell position, they actuate a pressure-switch-controlled circuit which raises the work and table to an easy exit position for movement of the work to a roller conveyor feeding a transfer machine. The pressure imposed (between 850 and 1300 lb) on the bushings by the ram is adjustable to meet varying requirements. If a bushing is pressed in with less than a predetermined press-fit, visual and audible signals are given to the operator.

ELECTRONIC PHOTOGRAPHIC ENLARGER

By eliminating conventional methods of " dodging " or shading certain parts of negatives by hand, in order to obtain uniform exposures during enlarging, a new electronic photographic enlarger announced by E.M.I. Electronics Limited, of Hayes, Middlesex, is stated to produce perfect enlargements from poor-quality negatives, even with relatively unskilled personnel.

In the new enlarger, believed to be the first of its kind in Europe, guesswork and the operating skill normally required for producing good enlargements from many negatives are entirely eliminated by electronic techniques, in which a beam from a cathode-ray tube is used to obtain automatic shading and exposure control. The cathode-ray tube produces a highly actinic " cold " scanning light beam which covers the negative approximately once per second. When the exposing spot of light from the tube encounters a dense region on the negative, it immediately becomes brighter. Similarly, the brightness of the spot is reduced for thin regions on the negative, thus ensuring maximum print detail in both highlights and shadows.

A special light-integrating system terminates the exposure automatically, producing uniform print density, without the need for adjustment to compensate for widely varying negative densities. Thus, temperature batch-processing can be carried out, if desired, all that is

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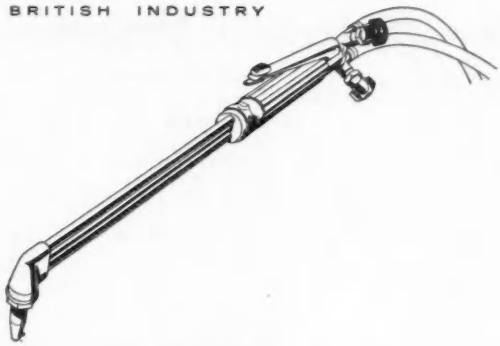

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required of the operator being to preset for paper speed, processing, and required print density.

The new enlarger is capable of printing from 35-mm negatives up to half-plate negatives, and provides a maximum printing area of 30 × 40 in.

TAPE WITH ADHESIVE ON BOTH SIDES

A new tape, which has adhesive on both sides, is announced by Evode Ltd., of Stafford. Designated "Twinstik", the tape consists of a thin tissue which is impregnated with a special pressure-sensitive adhesive protected with a treated paper. Available in a variety of widths up to 12 in., it can be applied to most surfaces to provide a strong durable bond. The method of application is extremely simple :—The tape is unrolled and applied by hand to a surface and the paper cover is peeled off. This leaves the outer adhesive surface exposed, and it is to this surface that light articles or sheet material can be applied to form an immediate bond.

The adhesive is strong, exerting a considerable pull, and the cohesive strength afforded is combined with excellent ageing properties, transparency, and ultra-violet resistance. Furthermore, the absence of solvents in the adhesive surfaces of the tape makes it suitable for use on cellulosed and other surfaces.

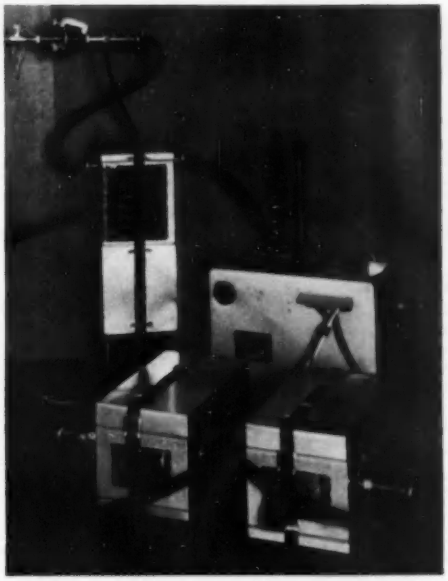
PNEUMATIC LEAKAGE TESTER FOR COOLER TUBES

A new, fully automatic leakage tester for cooler tubes, recently developed by Steel City Testing Machine, Inc., of Detroit, Michigan, not only provides a simple and effective means of checking for leaks, but is capable of testing approximately 2100 parts per hour, with positive rejection when leaks are encountered.

A pulley-operated hopper feeds tubes into slots in a 16-station drum. When the drum revolves to a filling position, an air pressure of 50 psi is applied to the tube. Satisfactory parts complete a 260-deg. cycle and are ejected at the front of the machine. Leaking tubes are automatically ejected at the rear of the machine. The 16-station drum, of 12-in diameter, normally rotates at a speed of 2·2 rpm, speed being determined by the holding time specified for the test. Exceptionally easy to operate, the machine has no valves, and the pressure regulator incorporates a device to keep the drum lubricated.

ISOKINETIC SAMPLING APPARATUS FOR DUST AND FUMES

Specifically designed for the isokinetic sampling of industrial fumes and dusts, including the collection and estimation of such samples, the new isokinetic sampling apparatus announced by the Longworth Scientific Instrument Co. Ltd., of Abingdon, Berks., permits rapid sampling with a minimum of calculations of results. Furthermore, as access to ducts and chimneys is often difficult, the use of separate units with flexible connections permits various parts of the equipment to be distributed in convenient locations, thus enabling it to be used in cramped or otherwise inaccessible positions and increasing considerably its range of application.



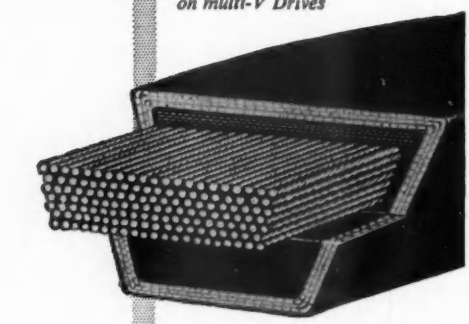
The apparatus, known as the Longworth Isokinetic Sampling Apparatus ("LISA"), was originally developed by the British Iron and Steel Research Association and essentially consists of five linked units, i.e., a sampling probe, a filter unit, a cooling coil, pump units, and an instrument unit. In addition, a combined Pitot tube and pyrometer is provided for measuring gas velocities and temperatures respectively.

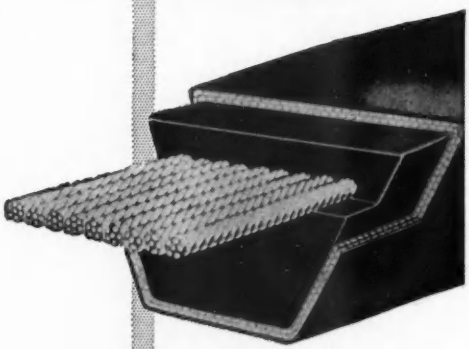
In operation, the stainless-steel probe faces directly into the stream of dusty gas and a sample is withdrawn isokinetically, i.e., it flows into the nozzle in the same direction and with the same velocity as the local undisturbed gas stream, so that the dust content of the sample accurately represents that of the main gas stream at that point. The sample is then drawn through the weighed filter and cooled to ensure that corrosive liquids are not condensed in the sampling train. Two gas-tight vane pumps, equipped with by-pass valves and connected in parallel, then expel the filtered and cooled gas sample through a gas flow-rate indicator and an integrating meter. The filter is then re-weighed, and the concentration is obtained by dividing this mass by the volume of the gas sample.

In order to sample isokinetically, the gas velocity and temperature in the stack are measured with the combined Pitot tube and pyrometer and indicated on the inclined gauge and millivoltmeter in the instrument unit (shown in the right background of the illustration). Simple two-column tables are then used to relate this gauge reading to the isokinetic sampling rate, which is maintained by operating one of the by-pass valves. This simple method

V-BELTS THAT ARE BUILT TO LAST!

on multi-V Drives





and on F.H.P. Drives

YOU BUY ENDURANCE when you buy Goodyear V-Belts, made in types and sizes to suit every job from the largest multi-V installations to small F.H.P. drives. Longer belt life, more efficient transmission, less risk of costly shutdowns — these are the positive benefits of making good use of the Goodyear ' job-designed ' range of belts which are backed by more than fifty years' experience in rubber engineering.

To be sure of longest, most economical performance it pays to consult Goodyear or your Goodyear Industrial Distributor, who will recommend a suitable belt, and also advise on installation and maintenance.

GOODYEAR

V-Belts · Conveyor Belting · Transmission Belting · Hose · Fenders

THE GOODYEAR TYRE & RUBBER COMPANY (GREAT BRITAIN) LIMITED · WOLVERHAMPTON

of flow-rate control is made possible by placing the meters after the pumps, where gas pressures and temperatures are virtually constant.

As rates of gas and fume emission from steelmaking processes can vary rapidly, the sampling train must collect a weighable sample of dust and fume very quickly. A robust filter assembly has accordingly been designed which incorporates a throw-away filter of graded glass fibres, held in a re-usable stainless-steel canister, the whole of which can be weighed on a chemical balance. The filter pads will filter iron-oxide fume from corrosive gases at 300°C at a rate of 3 cfm, whilst the sampling probe and Pitot tube can withstand a temperature of 650°C.

RADIATION WARNING INSTRUMENT

A new warning device of the ionization-chamber type, which gives a loud warning on receiving a gamma dose of 30 milliroentgens is now produced in portable form by Radiatron, of Richmond, Surrey.

The instrument, which also responds to beta rays and which weighs only 12½ oz, uses transistors and is battery-operated. The batteries have a capacity of 220 mA-hr and, as they are discharged only during emission of the signal and no current is drawn during measurement, they are capable of operation for from 2 to 3 months under normal conditions. The batteries used can be recharged *in situ* by means of a small mains-operated charger, which weighs only a few ounces and can be plugged directly into the instrument.

The monitor has a flat response to radiation energies ranging from under 100 kV to 3 MV — an important consideration, in view of the fact that, in most cases, the radiation is composed of various energies, owing to Compton scatter. Headphones may also be plugged into the monitor. The instrument utilizes its own source of calibration, this being a small beta source normally housed in a lead-lined container. The operator checks correct operation of the instrument by placing the source in position on the monitor, and using a stop-watch and a calibration sheet supplied with each instrument.

The new warning device, which is intended to be a complementary instrument to other types of radiation-protection monitors, is especially useful when operators are engaged on work in which their hands are not free, or where the attention or skill demanded for reading other types of instruments cannot always be depended on. Similar instruments, operating on a higher dose than 30 milliroentgens, can be made for special requirements.

SPRAY-APPLIED SOLUTION FOR PROTECTING BULK MATERIALS

A new compound for blanketing and protecting outdoor storage piles of bulk materials against loss from wind or rain erosion has been developed by the Johnson-March Corp., of Philadelphia, Penn. The spray-applied solution, designated "Compound SP", contains specially developed additives for maximum coverage and penetration, and is a blend of synthetic, organic, long-chain polymers in a water base, forming a thin crust which is tough, durable, and highly resistant to weathering. In a series of heavier concentrations adaptable to a wide range of material composition, particle size, and climatic conditions, these solutions are suitable for coating stock piles of bauxite, carbon, chromite concentrations, coal, fluorspar, ilmenite, silicon carbide, sulphur, and many other types of materials in outdoor storage piles.

The crusts formed are stated to reduce the serious economic losses suffered each year through the disappearance of large tonnages of valuable material. In addition, community or plant-dust nuisances are abated. Protection lasts for periods in excess of a year, and the compound itself is inert, unreactive, non-toxic, and without adverse effects on the burning qualities of coal or the subsequent processing of sulphur, metal ores, carbon, etc. Application is easily accomplished with any type of spraying equipment. If desired, the solution can be supplied with a colour indicator, to show where protective treatment has been made.

METHOD OF MARKING METAL SURFACES

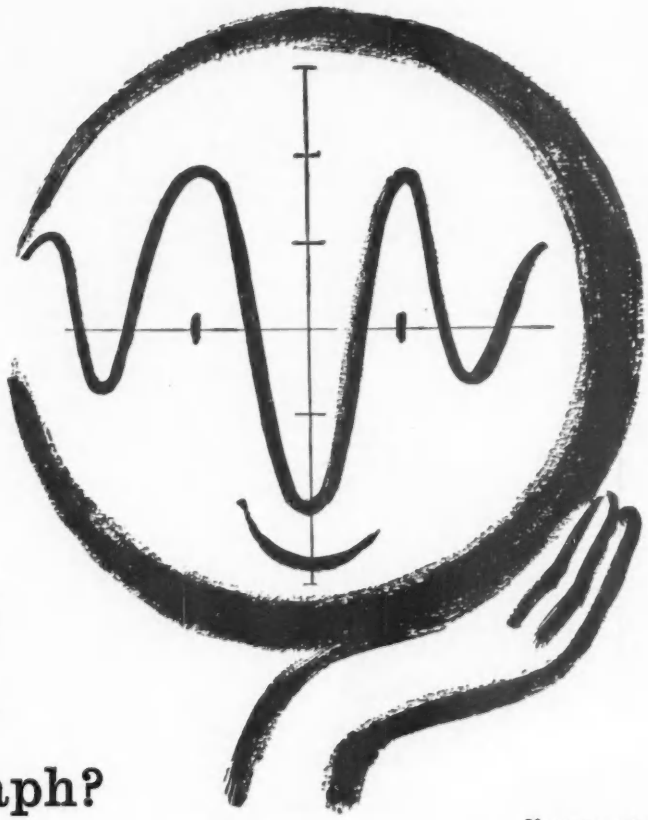
A new method of marking metal surfaces, involving the use of a special duplicator stencil, has been devised by Ellams Duplicator Co. Ltd., of London, W.1. The method, which is simple, rapid, and economical, can be used to reproduce trade-marks, identification numbers, etc. on tools, machinery, and metal products of all kinds.

The stencil is used in connection with an electro-chemical etching machine. When the stencil (which is non-conducting and resists the electrolyte) is placed in contact with a metallic surface, words, figures, and designs can be imprinted on the metal surface. Provided that a black-and-white original can be supplied, it does not matter how complex the original design may be, as it is reproduced faithfully in every detail on the stencil by means of an electronic stencil cutter. A source of light scans the original black-and-white design and, through the medium of a photo-electric cell, electrical impulses are generated, causing the stencil to be perforated in the areas corresponding to the black portions of the original.

SELF-SEALING SWIVEL JOINT

Available in a wide range of sizes and materials for use with air, steam, water, etc., the "Hilyn" self-sealing swivel joint, produced by Hilyn Industrial Equipment Limited, of Enfield, Middlesex, is a simple and practical method of solving the problems associated with reciprocating and rotary movement in rigid pipework, particularly in those cases where the use of flexible hoses is not practical by reason of original plant design or space restrictions.

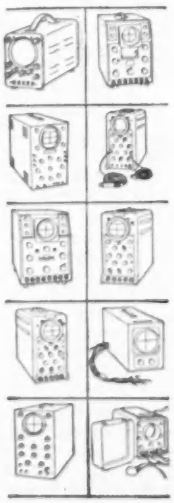
The joint, which incorporates only five component parts, requires little or no manual adjustment and is normally suitable for use at pressures up to 500 psi and temperatures up to 485°F, though special designs can be supplied for higher pressures and temperatures. The joint utilizes a P.T.F.E. seal, self-sealing and pre-tension being achieved by the internal pressure, in conjunction with a specially tensioned spring, which ensures a completely pressure-tight joint, even at very low pressures. Automatic adjustment of pipework misalignment can be effected through 360 deg., without restricting flow, and the design also caters for an angular or side movement of 10 deg.



Thinking about an oscillograph?

If you are experienced in the design of high quality instruments, our Technical Director would be glad to hear from you.

FOR USE IN ELECTRONICS? From the wide range of single and double-beam instruments, a model is available to suit the requirements of all sections of this expanding industry.
IN INDUSTRY? Diverse industries are finding solutions to their design and production difficulties with the aid of the Cathode Ray Oscillograph. Our Technical Advisory Service will be pleased to help you with your specific problem.
IN SPECIALISED FIELDS? Unusual types of oscillograph have been designed for specialised applications in the Hydraulic, Marine and Ultrasonic fields. We shall be pleased to consider specific development projects.



For technical information, write to:

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The Instrument Company of the Cossor Group

COSSOR HOUSE, P.O. BOX 64, HIGHBURY GROVE, N.5, ENGLAND
Phone: CANonbury 1234 (33 lines). Grams: COSSOR NORPHONE, LONDON. Codes: BENTLEY'S SECOND. Cables: COSSOR LONDON
TAS/CI.I

NEWS OF THE MONTH

PERSONAL

Mr. Ralph Gabriel has been appointed managing director of Charles Churchill & Co. Ltd., the parent company of the Charles Churchill group.

Dr. M. F. Jordan has joined Murex Welding Processes Ltd., of Waltham Cross, as leader of the Fundamental Research section of the Research Department, succeeding **Dr. W. D. Biggs,** who has now left the company to take up an appointment in the Engineering Department of Cambridge University.

Mr. L. R. Newing has been appointed Outside Sales Manager for home sales of E. H. Jones (Machine Tools) Limited, of Hove. **Mr. H. M. Lebrecht, A.M.I.Mech.E.,** who has been manager of the Special Machinery Sales Division for some time, has been appointed Inside Sales Manager. **Mr. G. Cranston** has been appointed area manager for Scotland, and a new office and showroom will shortly be opened at Wilson Place, Nerston Industrial Estate, East Kilbride.

Mr. H. Morley, deputy general works manager of Samuel Fox & Co. Ltd., a subsidiary of The United Steel Companies, Limited, has been appointed general works manager, in succession to **Mr. J. D. Joy,** who has been appointed director and general works manager of the Appleby-Frodingham Steel Company with a view to becoming deputy general manager in 1959.

British Insulated Callender's Cables Limited announce that **Mr. O. W. Minshull, B.Sc., M.I.E.E.,** has been appointed general manager of their Power Cables Division. Mr. Minshull will remain deputy chairman of British Insulated Callender's Construction Company Limited and of British Insulated Callender's (Submarine Cables) Limited.

Mr. N. S. Billington, M.Sc., M.I.H.V.E., who has been head of the National College for Heating, Ventilating, Refrigeration, and Fan Engineering since 1950, has resigned to take up the appointment of Director of the Heating and Ventilating Research Council. Mr. Billington is succeeded by **Dr. David R. Scott,** who was a Senior Lecturer on the staff of the Royal College of Science and Technology, Glasgow.

MR. F. A. LANGHAM

It is with regret that we announce the death, on August 12, at the age of 50, of Mr. Frank Arthur Langham, who, for nine years and until recently, was Rotating Plant Sales Manager of Crompton Parkinson Limited, with whom he served for seventeen years.

BUSINESS NOTES

The Owen Organisation announce that they have acquired the business of "**Mechanair**", formerly carried on by **Acocks Engineering Co. Ltd.** Mr. J. E. Kavanagh, the former managing director of Acocks Engineering Co. Ltd., will be in charge of the " Mechanair " division of **Rubery, Owen & Co. Ltd.**

The Industrial Furnaces Division and the Engineers' Tools Division of **Brayshaw Furnaces and Tools Ltd.,** Belle Vue Works, Manchester 12, are now trading as separate companies under the names of **Brayshaw Furnaces, Ltd.,** and **Brayshaw Tools, Ltd.,** respectively. The registered office of the two new companies will continue to be located at the Belle Vue Works. A branch office for Brayshaw Furnaces, Ltd. has been opened at 84 Blonk Street, Sheffield 3.

The headquarters of the **BTH Electronics Group** have been transferred from Rugby to New Parks Boulevard, Leicester (Tel. :—Glenfield 531), where the new offices and industrial electronics factory are situated. Military electronics and radar remain at Blackbird Road, Leicester, and valves and semiconductors at Carholme Road, Lincoln.

Dowty Equipment Limited announce that they have concluded exclusive licensing arrangements with the **Moog Valve Co. Inc.,** of East Aurora, N.Y., so that Moog servo-valves, used on aircraft, guided missiles, and industrial equipment, will be manufactured in Great Britain. The licensing agreement covers not only the U.K. but also the British Commonwealth (excluding Canada) and Western Europe.

A new subsidiary, **Servo Units Limited,** has been formed to handle all the servo-mechanism work of **Harvey Electronics Limited.** The address of the new company is 273 Farnborough Road, Farnborough, Hampshire (Tel. :—Farnborough 1120).

The address of the Nottingham branch of **Crompton Parkinson Ltd.** is now at Crompton House, Maiden Lane, Woolpack Lane, Nottingham (Tel. :—Nottingham 45678).

Parsons Marine Turbine Company, Limited, a member of the **Richardsons Westgarth Group,** have concluded an agreement for technical collaboration on the design and manufacture of marine steam turbines with **Brown, Boveri & Company, Limited,** of Baden, Switzerland. The

Proof against atmospheric corrosion and many chemicals, insulated, immune to mould, happy in temperatures up to boiling point, these clips have many uses. Sizes to grip range from ¼ to 2 inches and colours available are black, white, grey, blue, red and green.

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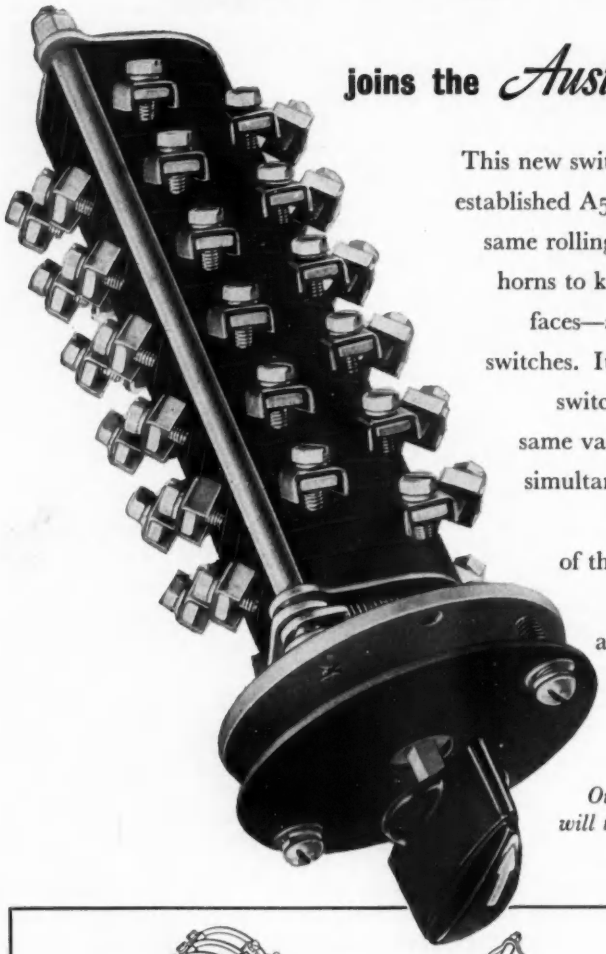
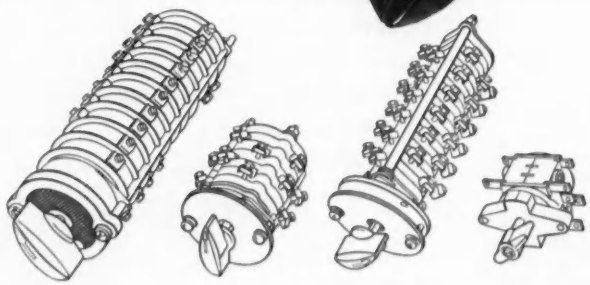


joins the *Austinlite* rotary switches

This new switch is identical in principle to the well established A50 and A30 rotary switches. It has the same rolling, self-cleaning contacts with extended horns to keep any arcing away from the contact faces—a feature exclusive to Austinlite rotary switches. It has a similarly powerful and positive switch mechanism, and can be built in the same variety of forms to switch in sequence or simultaneously very large numbers of circuits. It is extremely compact, the smallest of the Austinlite multi-cell rotary switches. It bridges the gap between the A30 and the little single-cell 10-amp switch. Delivery, on standard applications, can now be made in four weeks.

Our brochure "SIMPLIFIED SWITCHING" will tell you more about the advantages of Austinlite Rotary Switches. May we send you a copy?



The four Austinlite Rotary Switches—A50, A30, A15 and A10

Austinlite

ROTARY SWITCHES

tailor-made by

STONE-CHANCE LTD.

(Makers of Sumo Pumps and Stone-Chance lighthouses). Crawley, Sussex

Compagnie Electro-Mécanique, of Paris, who have been collaborating for more than fifty years with Parsons and with Brown, Boveri, will also be associated with this collaboration and development. In future, Parsons Marine will offer marine steam turbines of either Pametrada design or those arising from such collaboration.

The Incandescent Heat Co. Ltd., of Smethwick, has recently formed a Gas Atmospheres Division, headed by Mr. I. L. S. Golding. This Division will be responsible for the design, development, and sales promotion of gas and controlled-atmosphere generators and gas dryers.

Firth Cleveland Finance Ltd., of 8 Cleveland Row, London, S.W.1, a new project of the **Firth Cleveland Group,** concerned with financing hire-purchase transactions for all sections of the motor trade and for industrial plant, has opened up two branch offices. These offices are respectively at County House, 45 East Hill, London, S.W.18, and at 15/17 York Street, Sheffield 1.

The whole of the ordinary share capital of **Air Control Installations Ltd.** has been acquired by **Beyer Peacock & Company Ltd.,** of Gorton, Manchester.

Jenkins & Potter, consulting engineers, have moved their offices to 12/15 Great Turnstile, Lincoln's Inn Fields, London, W.C.1. (Tel. :—HOLborn 1291).

Stein Atkinson Vickers Hydraulics Ltd. have moved to a new address at 197 Knightsbridge, London, S.W.7. (Tel. :—KNIghtsbridge 9641).

CONTRACTS

Standard Telephones and Cables Limited, of London, W.C.2, have obtained two of the biggest submarine telecommunication contracts ever placed in the U.K. The first of these, an order for 530 nautical miles of undersea cable and submerged repeaters for the Anglo-Swedish cable project, providing the first direct telephone link between Britain and Sweden, is valued at £1,250,000, and will be the longest submarine telephone cable in Europe. The second order is for over 700 nautical miles of deep-sea cable, part of a new 36-channel telephone system to be installed next year between Miami, Florida, and San Juan, Puerto Rico. The value of the contract is $2,500,000.

A contract worth nearly £4,500,000 has been awarded to Australian Electrical Industries Pty Ltd., a subsidiary of Metropolitan Vickers, of Trafford Park, Manchester, by the State Electricity Commission of Victoria, Australia. More than £2,000,000 of the work, which is for a turbo-generator plant and electrical equipment for the new Yallourn Power Station in Victoria's Latrobe Valley, will be carried out in the U.K. Included in the new contract are two 120,000-kW turbo-generators, each complete with its own condensing plant, feed-water heating system, make-up water plant, and circulating water plant. Each turbo-generator will be suitable for steam at 1500 psig at 1050°F. The contract also includes six electrically driven boiler feed pumps, manufactured by Mather & Platt Ltd., three for each generator.

In addition, the State Electricity Commission of Victoria has awarded for the same project a contract valued at more than £5,000,000 to Babcock & Wilcox of Australia, a subsidiary of the British firm, for boiler plant. More than 20% of the work will be executed in Britain at the U.K. headquarters of the company. Included in the contract are two boilers suitable for operating continuously with raw brown coal. Each will have an output of 950,000 lb of steam per hour at a working pressure of 1600 psig and a temperature of 1060°F, when supplied with feed water at a temperature of 420°F.

Pirelli General Cable Works Ltd., an associate of The General Electric Co. Ltd., has been awarded a contract by British Railways, Southern Region, for the manufacture and supervision of the installation of the bulk of the high-voltage and associated cables for the second phase in Stage 1 of the electrification extensions to the Kent Coast. Some 140 miles of 3-core, 0·1-sq in., 33-kV, oil-filled cable and approximately 140 miles of pilot/supervisory cable are involved in the contract. For part of the route, corrugated aluminium sheathing will be employed for the feeder and pilot/supervisory cables.

W. C. Holmes & Co. Ltd., of Huddersfield, have received an order from Babcock and Wilcox Ltd., for two Holmes-Elex electrical precipitators to be installed after the two 200-MW reheat boilers, with pulverized fuel firing, at the West Thurrock Power Station of the Central Electricity Generating Board.

Crompton Parkinson Ltd. announce that they have secured an order valued at £250,000 from the Government of Ceylon for the supply, erection, and commissioning of three large transformer substations for the island's electrical development scheme. The substations, each of 25-MVA capacity, will be incorporated into a 33-kV distribution system for the City of Colombo. The order includes nineteen circuit-breakers of 750-MVA breaking capacity (to be manufactured by Cooke & Ferguson Ltd., a subsidiary company of Crompton Parkinson) isolators, busbars, lightning arresters, the whole of the outdoor steel work, and the control panels for the switchgear. Eighteen low-voltage units and four auxiliary transformers will also be supplied.

The six main transformers are each 12,500 kVA, 33/11 kV, with on-load tap-changing gear, and will be made in the company's Hayes Works. The first substation will be commissioned within fifteen months, and the whole contract completed in eighteen months.

9TH INTERNATIONAL CONGRESS ON ASTRONAUTICS

Attended by distinguished scientists from all over the world, the 9th International Congress on Astronautics was held this year at Amsterdam from August 25 to 29. Official British delegates were L. J. Carter and Kenneth W. Gatland, secretary and vice-chairman respectively of the British Interplanetary Society.

The central theme of this year's Congress was " Propulsion Systems and Propellants ". In all, nearly 80 papers were presented, including an inaugural lecture by Dr. Theodore von Karman, a first-hand account of the American " Explorer " satellite by Dr. Wernher von Braun, and a paper on photon drives by Dr. Eugen Sänger. Other contributions included " Electrical Propulsion Systems for Spaceflight ", by Dr. L. R. Shepherd, chairman of the British Interplanetary Society ; " Astronautics and Astronomy ", by George Gamow ; " Scientific Problems in Cislunar Space and Their Exploration by Rocket Vehicle ", by Professor S. F. Singer ; " Notes on the Immediate Feasibility of an Orbiting Astronomical Telescope ", by Dr. Fred L. Whipple ; " On the Development of Orbital Techniques ", by H. H. Koelle ; and " Considerations of the Solar Probe ", by R. P. Haviland. Other papers by B.I.S. members included " The Motion of an Earth Satellite on Re-entry to the Atmosphere ", by T. F. Nonweiler, and " Techniques of Analysing Terrestrial Radio and Optical Observations of Earth Satellites ", by R. H. Merson.

NEW FORDSON TRACTOR

For several years there has been a trend towards increased power in what is called the medium-power class of tractor. Thus, more power has been requested from the belt for threshing and baling, from the power take-off for forage harvesters and similar machines, and from the drawbar for heavy ploughing. As a result of this demand, the Ford Motor Company Ltd., of Dagenham, Essex, has now produced the Fordson " Power Major " tractor, which incorporates a more powerful, specially developed engine, without, however, sacrificing standards of fuel economy.

The new engine fitted to the " Power Major " pro-

PERFECTION in action

Singleness of purpose and years of experience lie behind any apparently effortless performance.
And so it is with springs.
It's taken for granted that Salter Springs will keep on and on, doing their job with smooth precision — indefinitely.
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THE **ALL – ACTION** SPRINGS

GEO. SALTER & CO. LTD. WEST BROMWICH, ENGLAND.
Established 1760

duces 51·8 bhp at 1600 rpm, as compared with about 41 bhp at 1600 rpm for the previous model (the Fordson " Major "), but with the same fuel economy. In addition, to cope with the increased output, the transmission has been suitably modified, and the opportunity has been taken to improve the comfort of the driver and to reduce fatigue. The throttle lever has been repositioned under the steering-wheel, enabling the driver to exercise finger-tip control, while retaining the use of both hands for steering, while the instrument panel is now located with all instruments neatly grouped below the steering-wheel.

BRITISH STANDARDS

(*Copies of British Standards may be obtained from the British Standards Institution, 2 Park Street, London, W.1*)

Pressure Containers for Paint and Other Substances (B.S. 1101 : 1958).

Extending its scope by providing for " pressure containers for ejecting by compressed air substances in addition to paint ", this revised 24-page illustrated standard (price : 6*s*.) relates to welded steel and cast aluminium-alloy cylindrical pressure containers not exceeding 33 in. i.d., with design pressures not exceeding 150 psi. Requirements are specified for materials, welding, construction and workmanship, and inspection and testing.

" B.S. 1101 " is one of five marks required to appear on each container manufactured in accordance with the standard.

Machine Screws and Machine-Screw Nuts (B.S.W. and B.S.F. Threads) (B.S. 450 : 1958).

Although the unified thread has been steadily gaining popularity since it was first introduced to British industry several years ago, it is recognized that Whitworth threads must inevitably continue in use for a long time to come. This new edition of B.S. 450 (price 12*s*. 6*d*.) has therefore been issued to meet the need for an up-to-date standard for machine screws with B.S.W. and B.S.F. threads.

The general requirements in the present standard are in most cases similar to those in B.S. 1981 (" Unified Machine Screws and Machine-Screw Nuts "), but, since development is continually occurring in methods of manufacture, further advances in established practice have also been recognized. In addition, the scope has been considerably extended to include all the various types of heads in common use in both slotted and recessed forms.

Classified Advertisements

The rate for all classified advertisements is 9d. per word : in bold print 1s. per word : minimum order 10s. Box-number advertisements 1s. extra. Instructions, together with remittance, must be received not later than the 1st of each month for advertisements to appear in the same month's issue.

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PADDLE BLADE FANS – VARIOUS SIZES – IN GOOD CONDITION

	PADDLE	MOTOR	SWITCHGEAR	INLET	OUTLET
1 off	5' 2" dia.	25hp	Ellison	3' 5" dia.	2' 6" sq.
1 off	4' 0" ,,	40hp	E.A.C.	2' 8" ,,	2' 0" ,,
1 off	5' 2" ,,	25hp	Ellison	3' 3" ,,	2' 6" ,,
1 off	5' 2" ,,	56hp	Ellison	3' 3" ,,	2' 6" ,,
1 off	5' 2" ,,	40hp	Ellison	3' 4" ,,	2' 6" ,,

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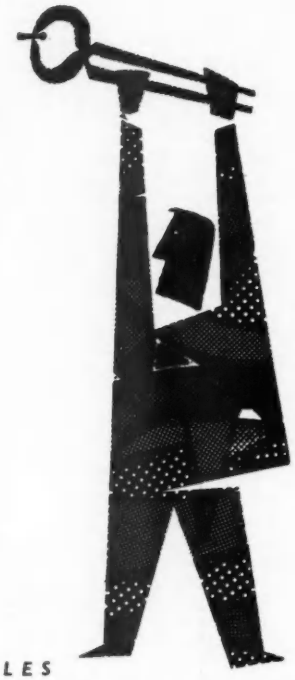

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LATEST INDUSTRIAL LITERATURE

1. Non-Metallic Silent Gears. A 24-page illustrated brochure describes non-metallic gears which are eminently suitable for high-speed drives, and which have noiseless properties, owing to the ability of the material to absorb vibration. As a result, wear on the mating wheel is practically eliminated and considerably reduced on the driving and driven machines. Tooth grinding, with its resultant high manufacturing costs, so necessary for the silent operation of high-speed metal gears, is not required with these gears, and thus they provide a means of obtaining a silent drive at a minimum of expense. Furthermore, there is no necessity to enclose the gears, as bath or spray lubrication is not required.

The chief advantages of employing this type of drive, apart from those mentioned, are low initial cost, maximum efficiency, positive drive, small space, and possibility of running the gears dry to avoid contamination from oil, where this is absolutely essential. A few of the applications mentioned are in compressors, machine tools, pumps, rolling mills, woodworking machines, and textile machinery.

2. Automatic Process and Temperature Control Valves. Full details are given in a well-produced 48-page catalogue of a new range of magnetic valves for automatic process and temperature control, together with information on valves available for special applications. These valves and ancillary equipment can be arranged for any application where the control of liquids and gases, etc., is required. In addition to eliminating the human element and providing a reliable, simple, and inexpensive means of control, they provide an improvement in the quality of the product, economy in fuel consumption, reduction of labour cost, and protection of valuable equipment. A number of useful charts and conversion tables is included, as well as a section devoted to general data on magnetic-valve installation and service.

Ancillary equipment dealt with includes rectifier sets, thermostats, electrothermal links, pipe strainers, magnetic control switches, and engine emergency cut-out switches.

3. Air Control Valves. Specially presented to permit selection of the required items in the shortest possible time and with the minimum of trouble, a 46-page illustrated catalogue deals fully with a range of air-control valves of the hand-, foot-, pilot-, and solenoid-operated type, air cylinders, ejection sets, blow guns, quick-acting couplers and ancillary equipment, and air-control hook-ups. Speedier operation, elimination of worker fatigue, and freedom from accidents quickly repay the installation costs and lead to expanded production at lower cost. The machines on which installations of the equipment are shown throughout the catalogue are of standard manufacture. Air rates and power charts included are based on generally accepted figures in use to-day.

4. Industrial X-Ray Equipment. A 6-page leaflet illustrates and describes two industrial X-ray units for 300- and 150-kV d.c. operation respectively, including details of industrial X-ray tubes. The maximum penetrating power in steel of the 300-kV unit is 120 mm with fluorescent screens and 80 mm with lead foils, and that of the 150-kV unit 50 mm with fluorescent screens and 28 mm with lead foils. Both units incorporate such features as the use of dry-type rectifiers, resulting in a well-damped operation of the tube and therefore no undue wear and tear of the tube, and of operation without supervision by means of voltage and tube-current stabilization.

Applications of the equipment include its use in welding, foundry work, heavy engineering, transport, and in steel and reinforced-concrete construction. The 150-kV unit is particularly suitable for testing workpieces of complex shape and difficult accessibility, as well as for radiography of light metals and plastics.

5. Flow-Coating Plant. A 6-page illustrated leaflet shows working production applications of the flow-coating method of painting. The advantages of this system arise chiefly where articles of considerable size are to be treated on all surfaces and where, with conventional dipping plant, such articles would require an uneconomical paint volume in the dip tank. Furthermore, parts of intricate shape liable to air trapping when dip-painted can be completely covered by the flow-coating method.

6. Pneumatic Tools. Details are given in an 8-page illustrated catalogue of a range of pneumatic tools for use at 85 psi, including drills, grinders, and hammers, as well as pneumatic accessories. The pneumatic hammers include a tool especially designed for using wire brushes of ¼-in. bore at the correct speed for best results, a special governor providing constant speed at all loadings.

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7. Bandsaw Machine for Metals with See-Saw Cut. Details (in English and German) are given in an illustrated leaflet of a horizontal-type bandsaw machine for metals, incorporating a special rocking or see-saw feature. As distinct from conventional metal-cutting machines, in which blade pressure must be adjusted in accordance with the diameter of the material, this see-saw movement eliminates the need for varying cutting pressure and saves considerable time in cutting operations, particularly in the case of large-diameter materials. When cutting thin profiles, where the see-saw movement would not offer special advantages, this movement can be disconnected by operation of a lever.

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8. Installation and Care of Electric Motors and Control Gear. Produced by a leading British manufacturer of electrical equipment, an extremely well produced and illustrated 82-page booklet provides a convenient and authoritative reference work on the installation and care of electric motors and control gear, including maintenance, diagnosis of faults, and the causes and effects of unsatisfactory performance.

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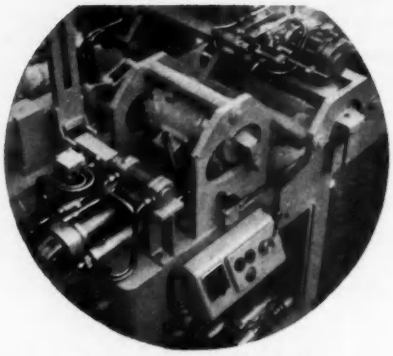

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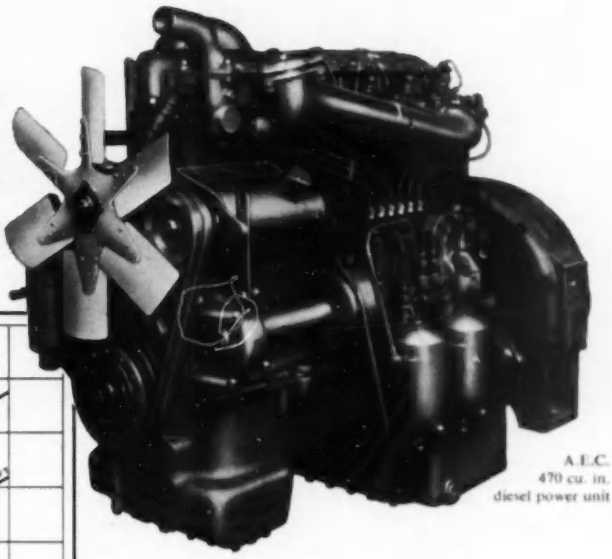

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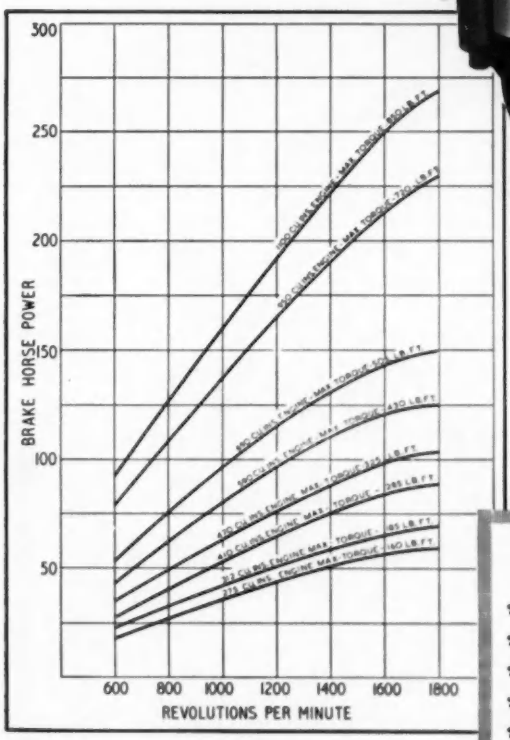

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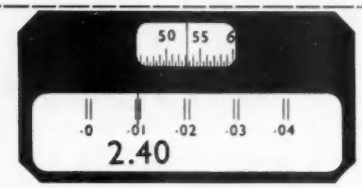

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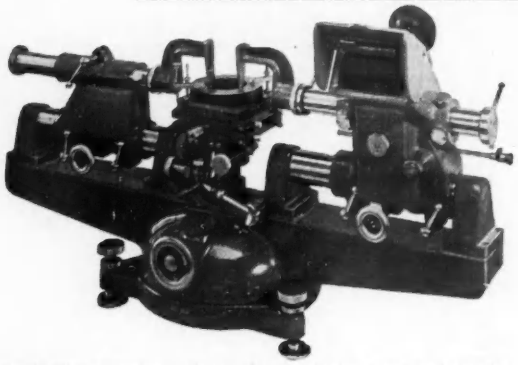

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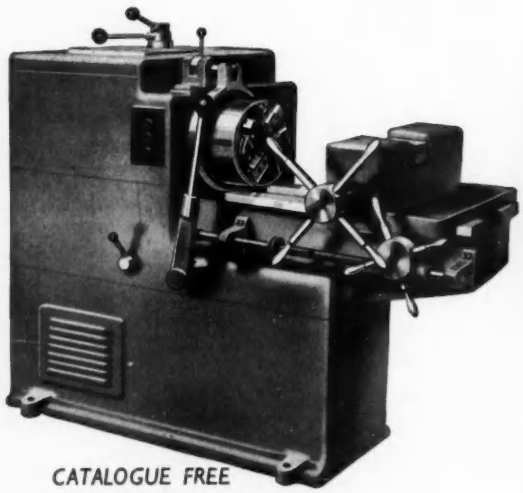

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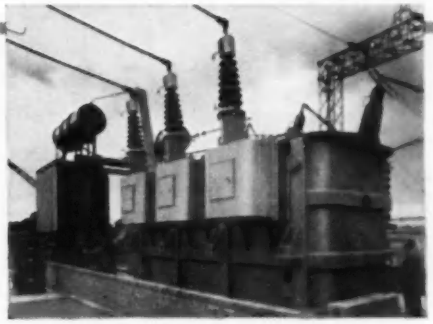

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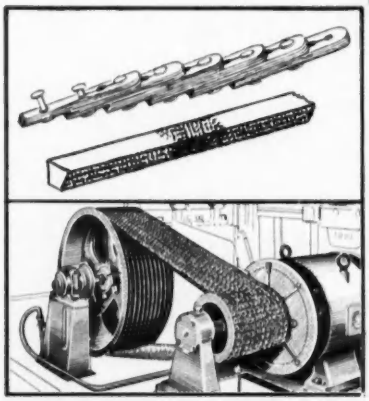

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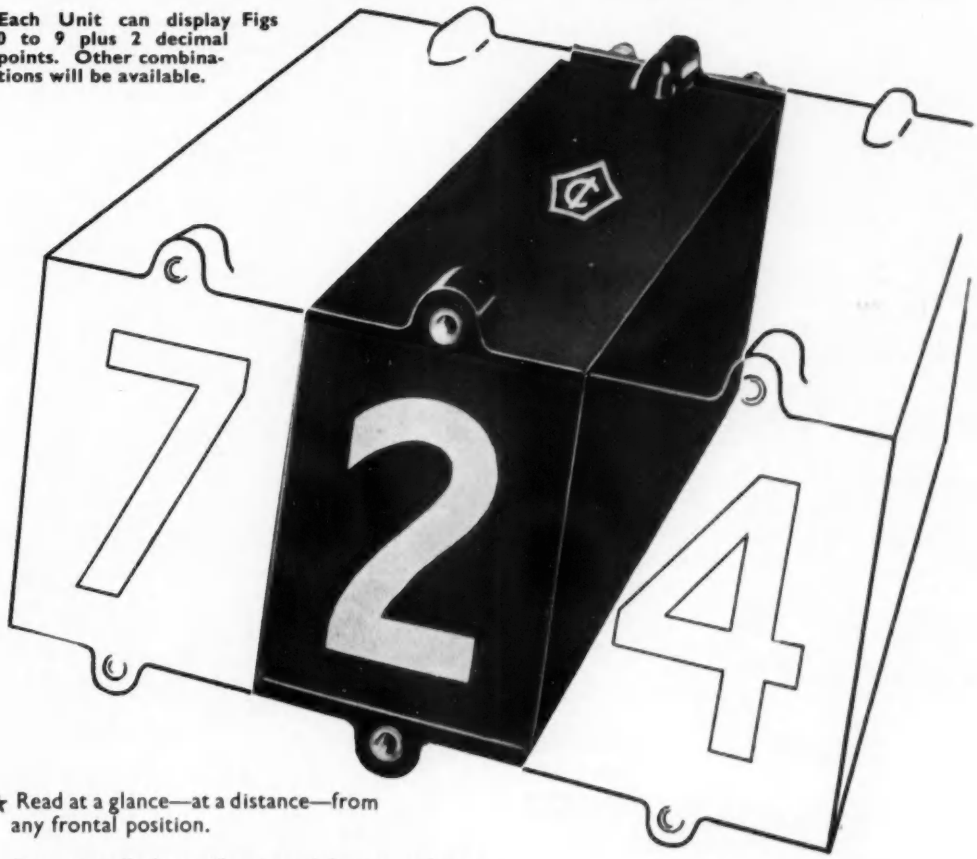

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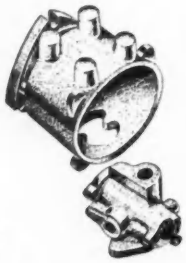

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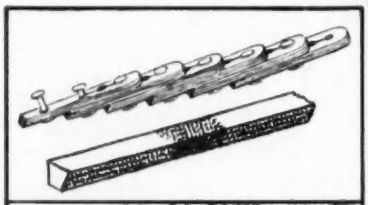

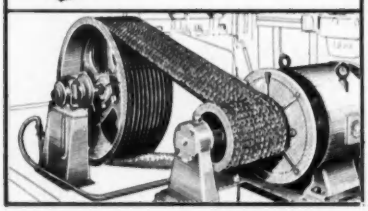

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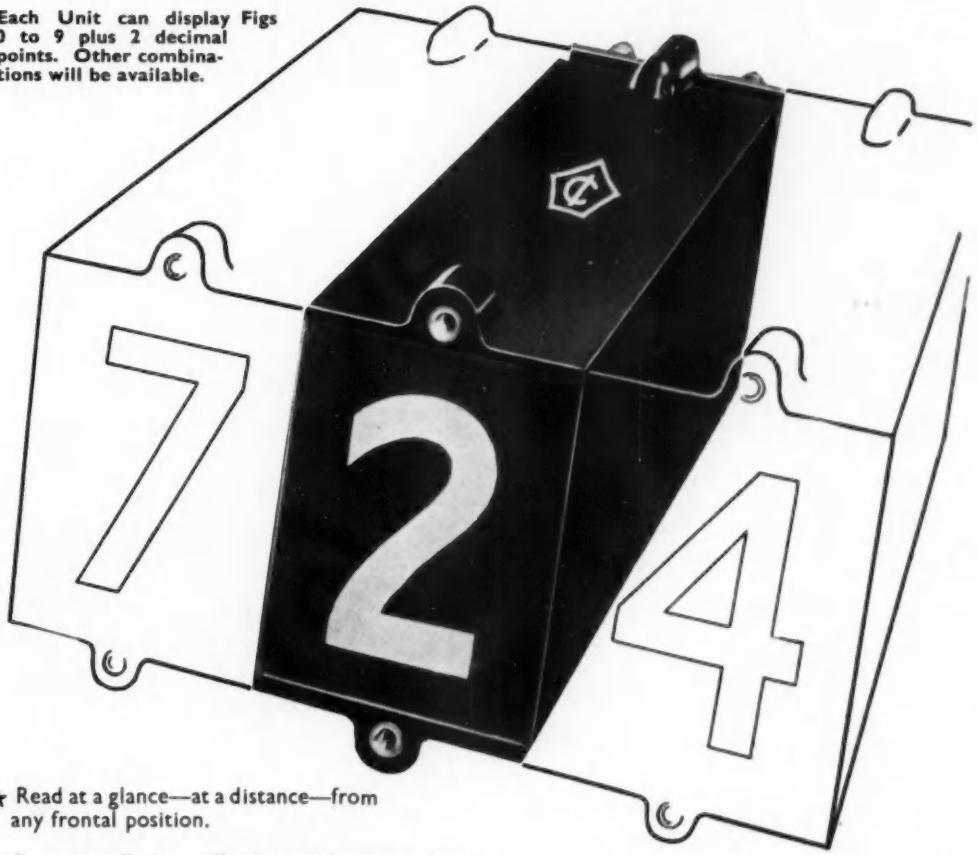

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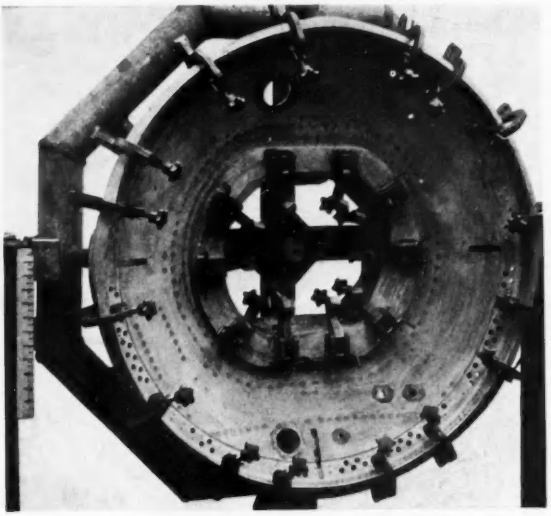

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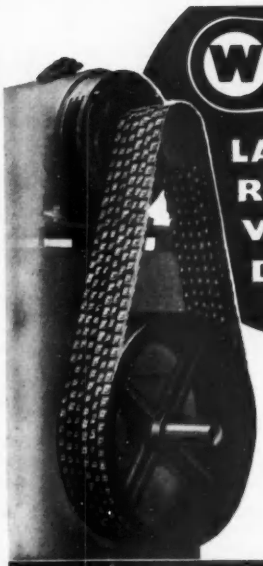

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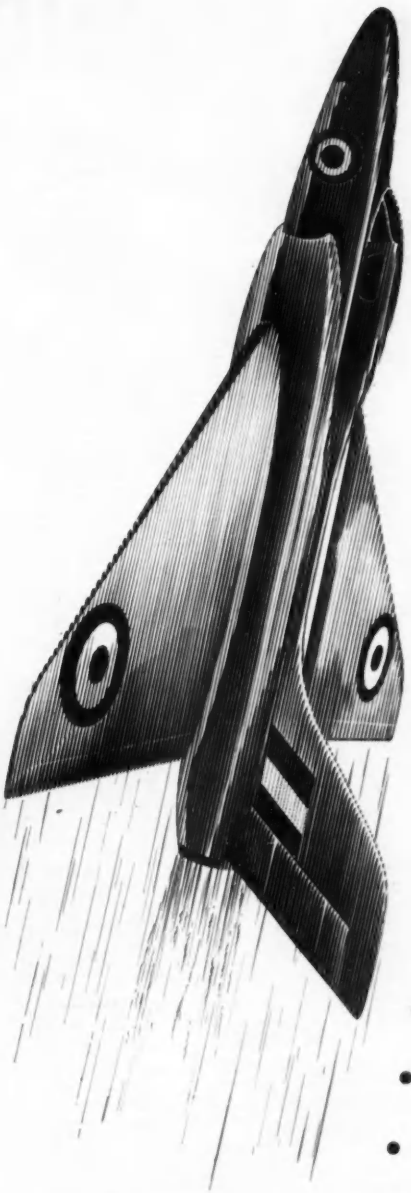

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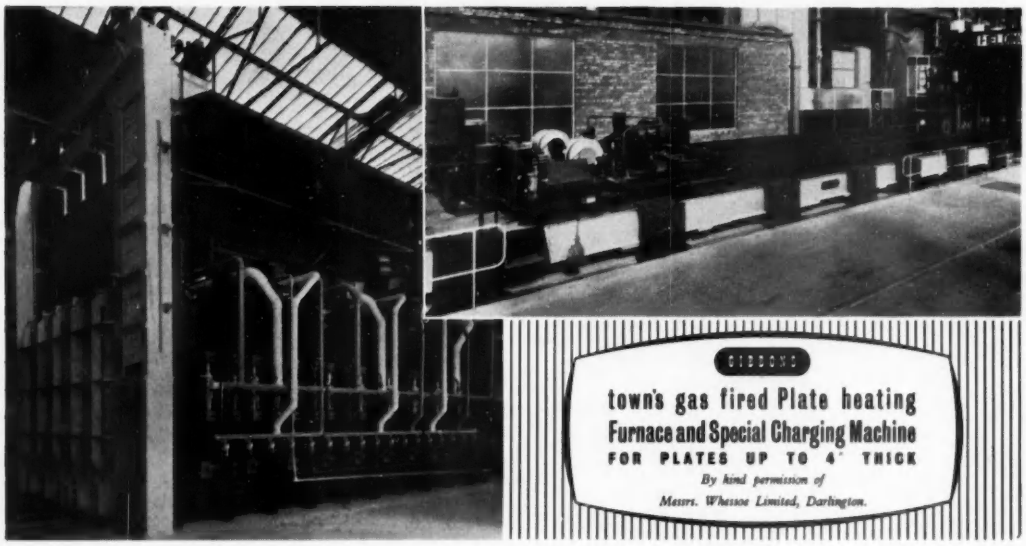

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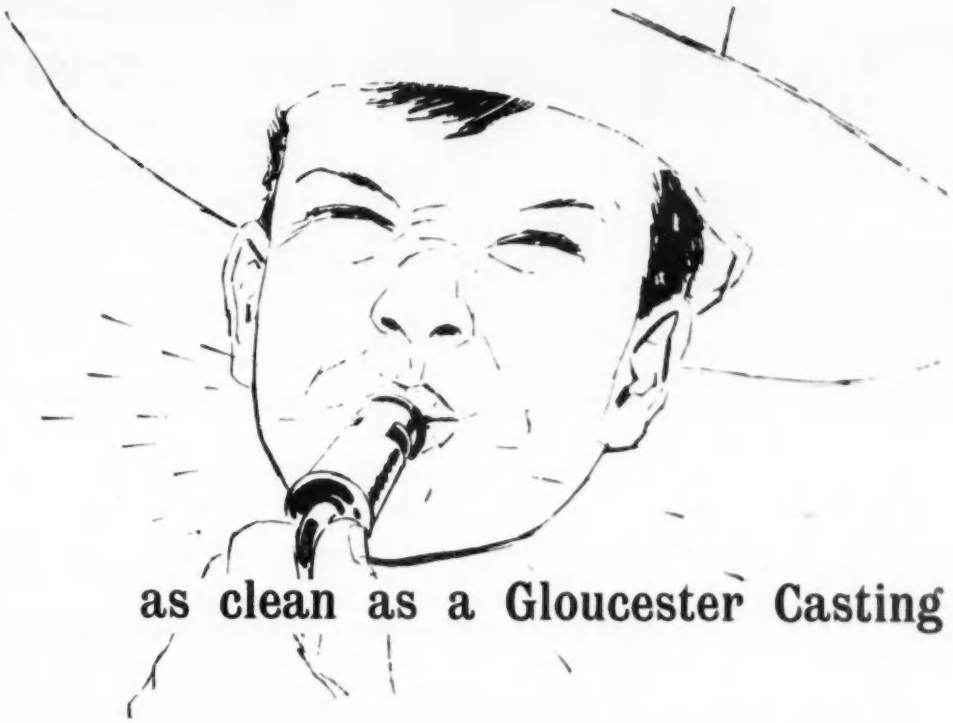

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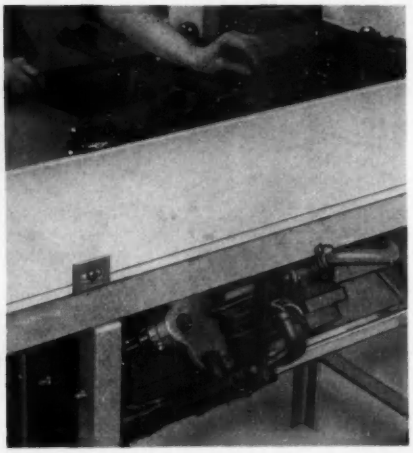

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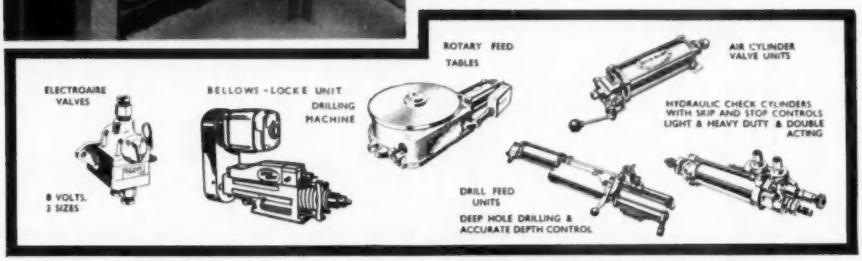
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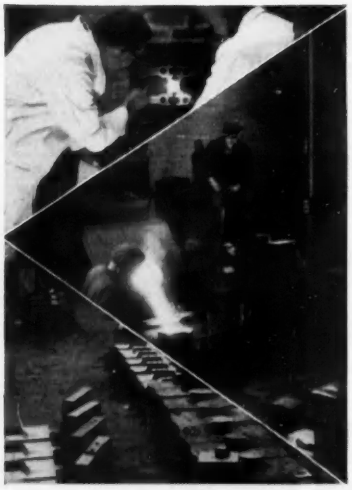

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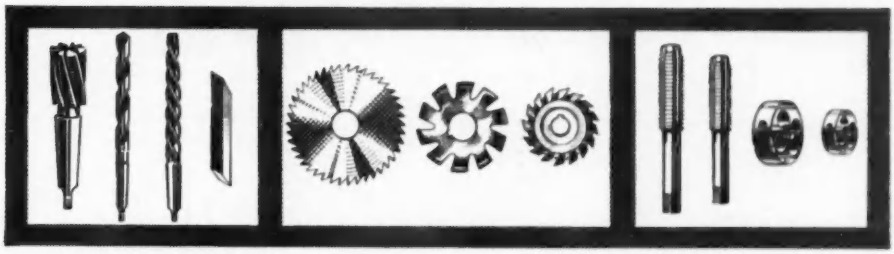

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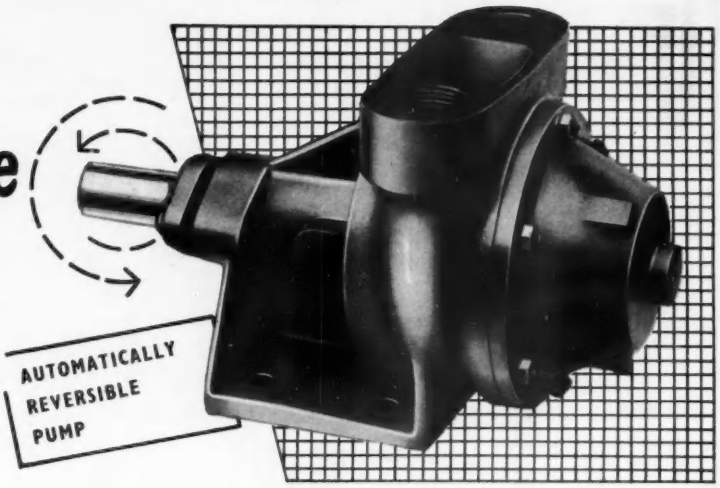

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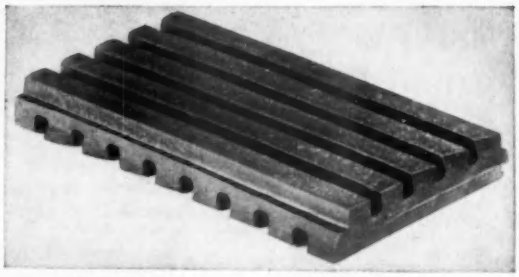

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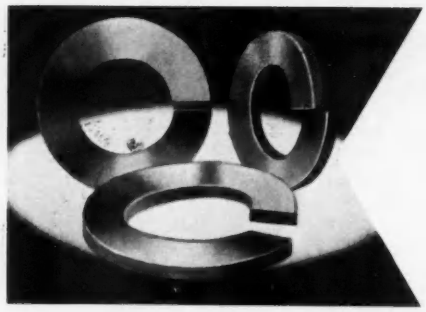

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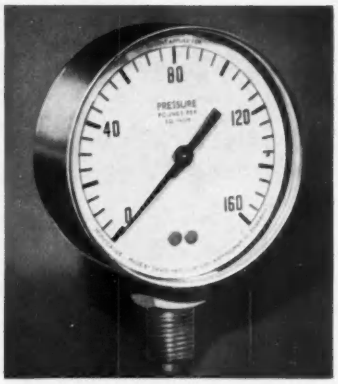

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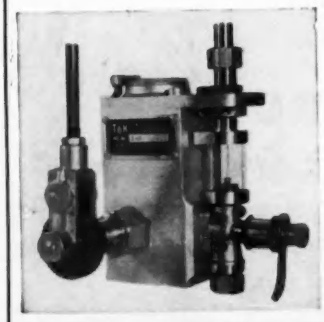

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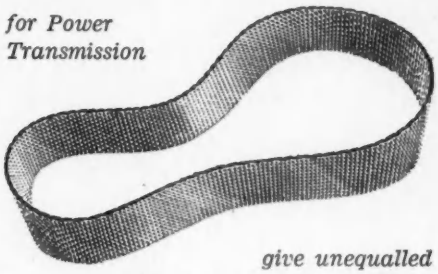

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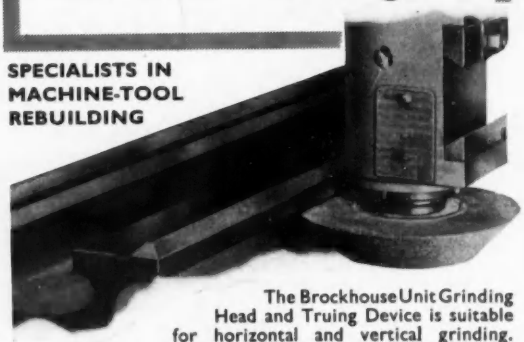

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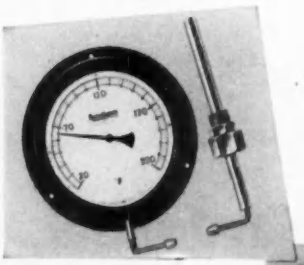

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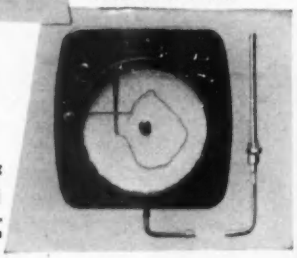

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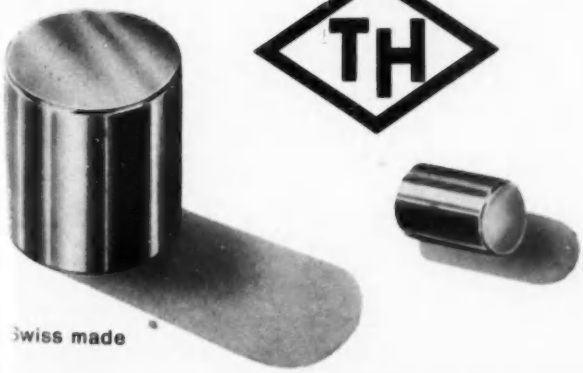

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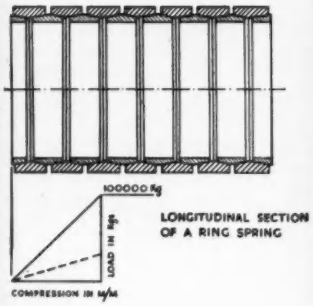

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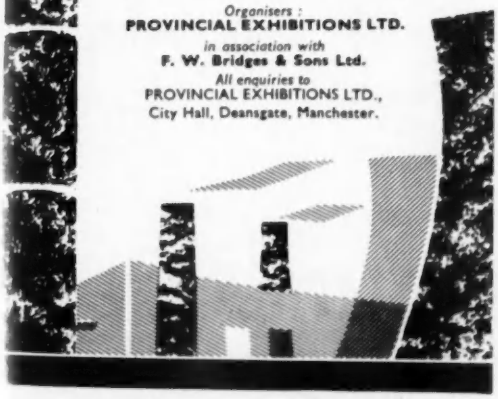

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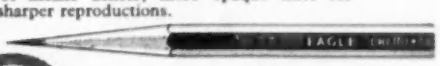

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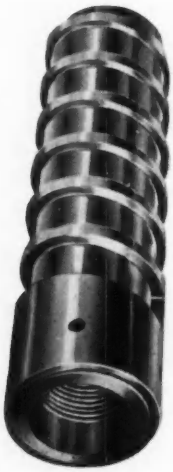

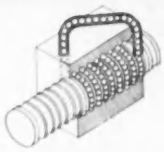

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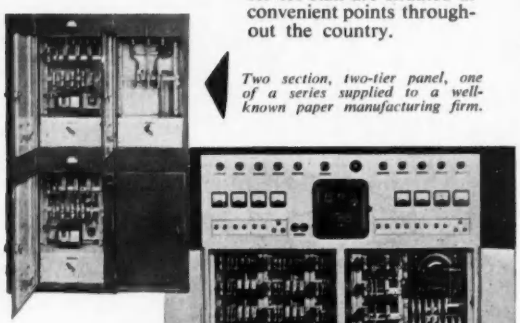

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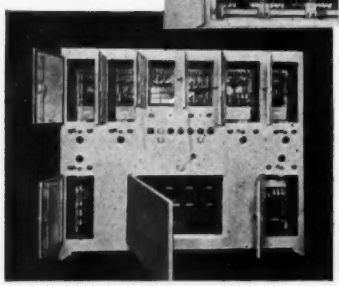

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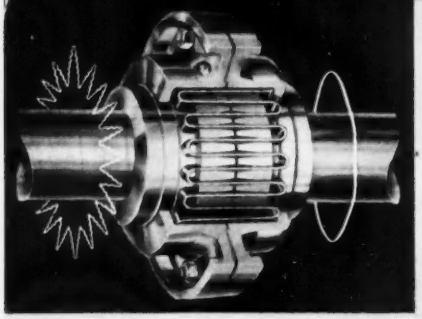

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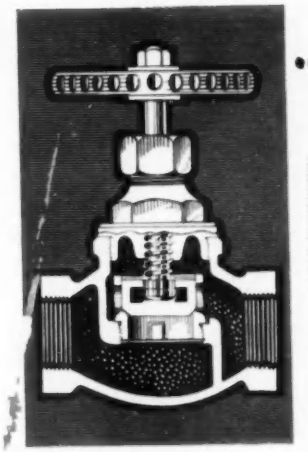

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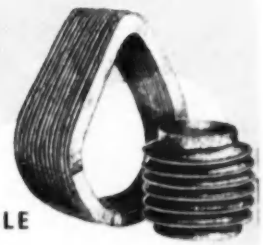

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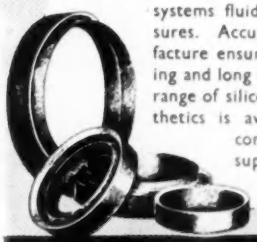

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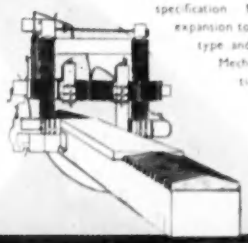

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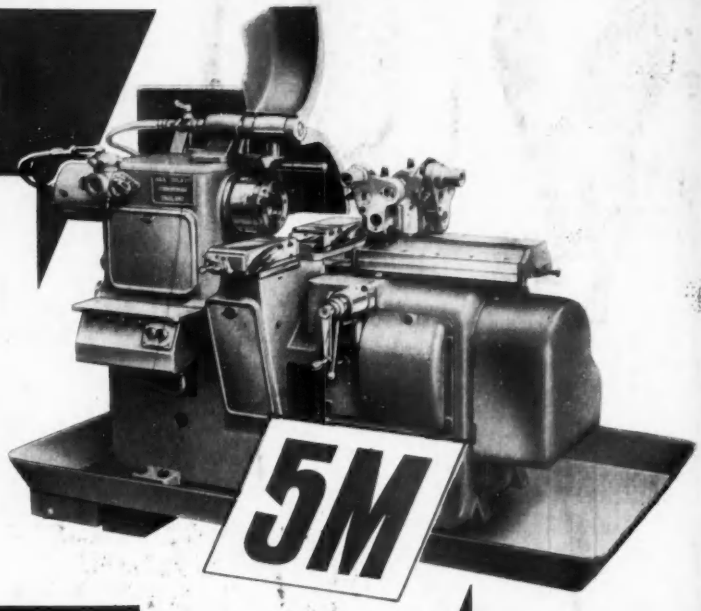
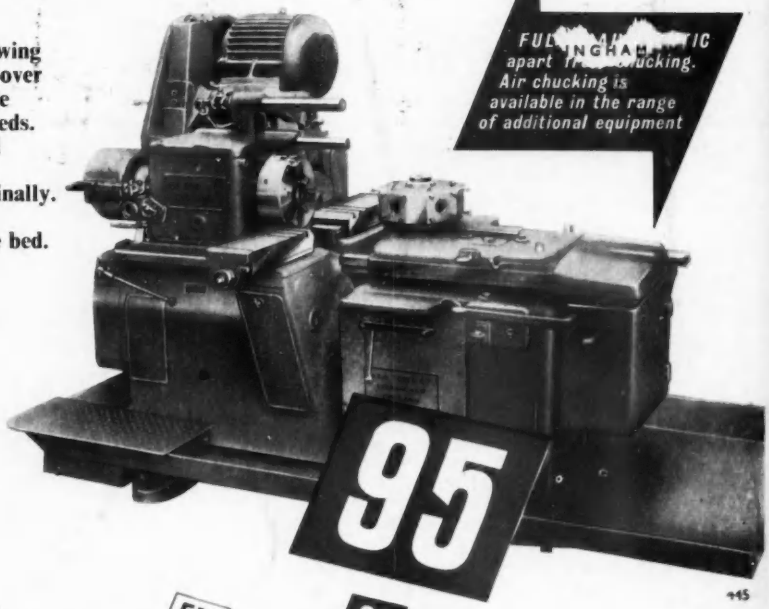


5M **Maximum swing 7¾". Swing over cross slides 6⅝". Independent motors for spindle drive and rapid motion to turret and cross slides. Wide range of speeds with three automatic changes. Suitable for small batch work.**

95 **Maximum swing 12½". Swing over cross slides 10¾". Wide range of speeds and feeds. Three automatic speed changes. Headstock adjustable 4¾" longitudinally. *FIVE* face turret; adjustable 2" along the bed.**

FULLY AUTOMATIC apart from chucking. Air chucking is available in the range of additional equipment



	5M ins	5M mm	95 ins	95 mm
Maximum swing	7¾	197	12½	317.5
Maximum swing over cross slides	6⅝	168	10¾	273
Cross slides stroke	2¾	70	4	101.6
Cutting travel of turret	4⅜	111	5¾	146
Number and range of spindle speeds	21 FORWARD 14 REVERSE 58 to 1458 r.p.m.		30 40 to 834 r.p.m. or 60 to 1220 r.p.m.	
Horse power of main motor	4½		10	

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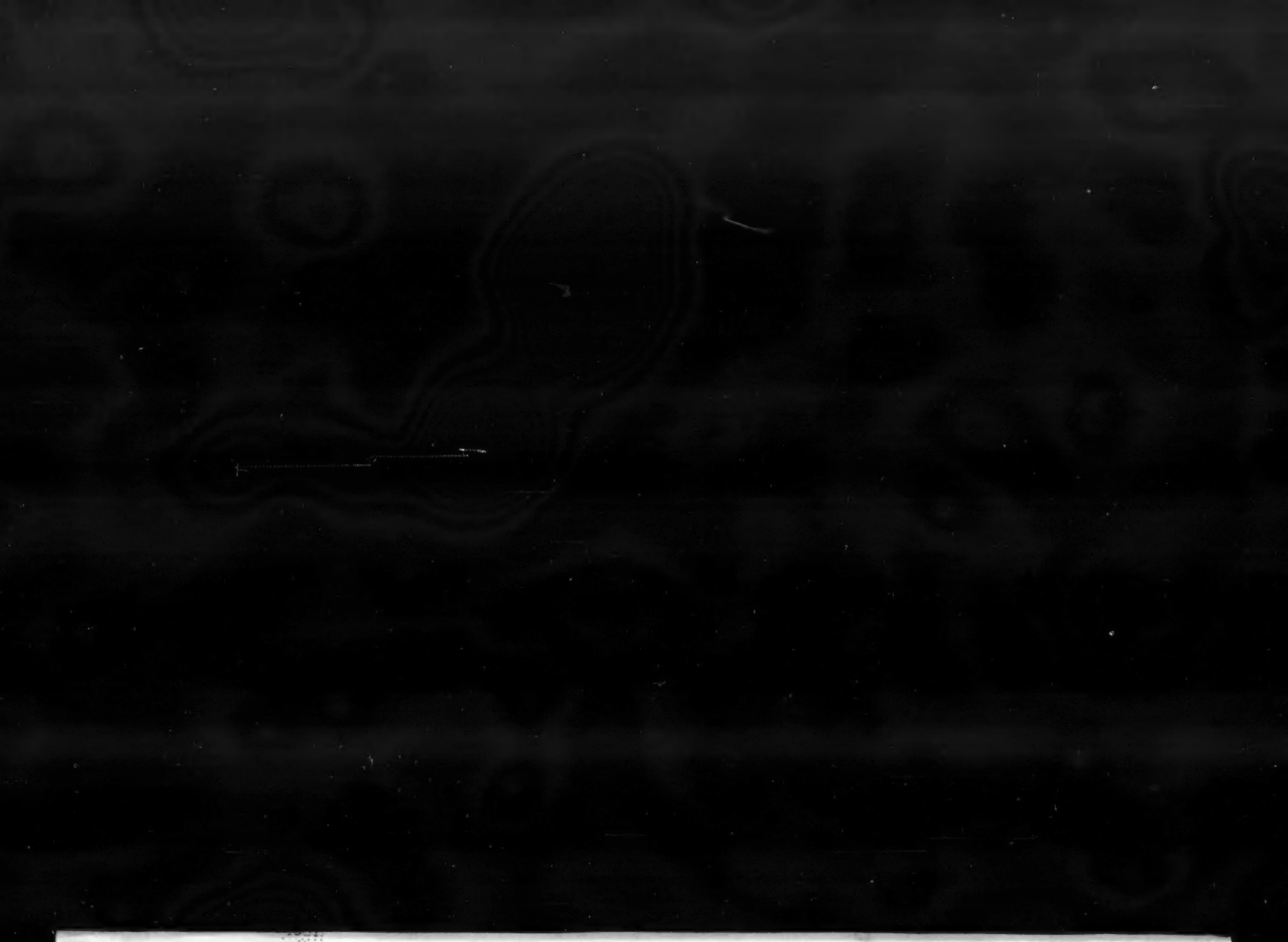
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